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An investigation of the effects of shear on the
compressive strength of plating

Ballard, John Adams

Massachusetts Institute of Technology

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AN INVESTIGATION OF THE EFFECTS OF SHEAR
ON THE COMPRESSIVE STRENGTH OF PLATING

JOHN A. BALLARD, JR.
BERNARD C. LENNON

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Cambridge, Massachusetts
May 20, 1949

Professor J. S. Newell,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Dear Sir:

In accordance with the requirements for the Degree of Naval Engineer, we submit herewith a thesis entitled "An Investigation of the Effects of Shear on the Compressive Strength of Plating".

Respectfully,

Cambridge, Massachusetts
May 20, 1949

Professor L. S. Brownell,
Department of the Physics,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Dear Sir:

In accordance with the requirements of the Office
of Naval Research, we submit herewith a letter which
has been prepared at the Office of Naval Research.
Respectfully,
Special Agent in Charge.

AN INVESTIGATION OF THE EFFECTS OF SHEAR ON THE COMPRESSIVE
STRENGTH OF PLATING

By

John A. Ballard, Jr.
Lieutenant, U.S.Navy
B.S., U.S. Naval
Academy, 1943

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Academy, 1942

Submitted in partial fulfillment of the
requirements for the degree of
NAVAL ENGINEER

at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

1949

thesis
P2

AN INVESTIGATION OF THE EFFECTS OF BLOOD IN THE CIRCULATION

STUDIES OF BLOOD

BY

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Submitted in partial fulfillment of the

requirements for the degree of

MAJOR

of the

NAVY

1944

ACKNOWLEDGEMENT

The authors wish to express their sincere appreciation and indebtedness to Professor Charles H. Norris for the suggestion of the apparatus and for guidance during the investigation.

APPENDIX

The author wishes to express his appreciation to the
State and Federal Governments in Washington, D.C.,
for the assistance and facilities provided for the
conduct of the investigation.

1934

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SUMMARY

Results

The testing apparatus constructed was successfully utilized in applying a compressive force and a shearing force to a plane, unstiffened, rectangular panel. Under combined conditions of loading, it was found that shear reduced the stability of a panel in compression.

Object

The purpose of this investigation was to design, construct, and test a device which was to be capable of applying a compressive force and a shearing force to a plane panel of plate. This device was then to be used to determine the combined effect of shear and compression on a panel of plate of a length-to-width ratio corresponding to the representative ratio of plating dimensions most often found in ship construction.

Procedure

The strain at the center of a plane, unstiffened panel was measured by strain gauges. The panel was compressed in a direction parallel to its longer sides and subjected to a shearing force applied in a diagonal direction which was further resolved into components along the four panel edges by a system of linkages. Measurement of compressive load was made by a balance scale and of shearing force by strain gauges located in the diagonal shear load apparatus.

Conclusions

It is possible to attain the combined condition of loading in the panel with this apparatus. Difficulty is encountered in attempting to duplicate test results using other specimens. Improper functioning of the apparatus and inconsistencies in assembly have caused erratic strain readings in the specimens tested.

Recommendations

Consistent results may be obtained from the apparatus if the components are very accurately machined and assembled. Modifications made on the present arrangements to insure that the specimen is unstiffened, freely supported, and subjected to a more uniform distribution of shearing force will facilitate further investigation.

10/10/1942

It is possible to make the system position of
locking in the hand with this system, difficulty is
encountered in estimating or defining the system using
other equipment. In some instances of the system
and information is available from these results. These
results in the system used.

10/10/1942

Current results may be obtained from the system
if the equipment are very carefully handled and exam-
ined. In some cases the results are not consistent in
nature that the system is modified, they are not
and subjected to a more serious situation of results
from all results through investigation.

INTRODUCTION

The application of the theories of elasticity and strength of materials to the structural design of ships has increased considerably in recent years. Limitations have been imposed upon the direct application of these theories for several reasons. The most important limitations are, first, that the structural members may be subjected to combined loading for which the theories may not apply, and, second, that the action of the members is governed by the method of assembly, degree of edge fixity, and the influence of adjoining structural members.

To insure that the most satisfactory structure will be obtained, it may frequently be advisable to verify experimentally the theoretical solution for the required design. An experimental analysis will, in many cases, indicate the efficiency and safety of the structure, and, in addition, may lead to a possible saving of weight, which is very important in ship design.

Several experimental investigations have been conducted on the compression of rectangular plates and on the buckling of plates under shearing forces. In 1937, Palmer and Pfingstag (4) made an experimental and theoretical investigation of the effect of end fixity on the strength of plating in compression. Reports of the United States Experimental Model Basin, the David Taylor Model Basin, and the National Advisory Committee for Aeronautics describe

experimental investigations conducted on stiffened and unstiffened plates under varying conditions and types of loading. A brief description of typical experiments on the buckling of plates is presented by Timoshenko (1).

An important condition existing in the side shell, decks, and bulkheads of a ship is the combined application of direct and shear stresses due to the working of the ship in a seaway, the condition of loading, or some other cause. The more serious condition is that of combined compression and shear. It has been suggested in (2) that an experimental investigation be made of the effect of shear on the compressive strength of plating. This suggestion has been accepted as the objective of this report.

In the field of aeronautics, an investigation of this combined condition of loading has recently been completed. The test specimen utilized in this report (5) consisted of a long, rectangular plate divided into a large number of rectangular panels by stiffeners spaced at regular intervals. The compressive force was applied in a direction parallel to the shorter edges of the panel, while, usually, because of the longitudinal arrangement of plating, in a ship the compressive force is applied parallel to the longer edges. The testing apparatus of this report (5) was designed in such a manner that a variation in degree of edge fixity along the longitudinal

experimental investigation conducted on 10/10/54 and
10/11/54 under various conditions and types
of loading. A brief description of typical results
on the loading of tubes is presented in Appendix (A).
In general, results indicate that the tubes
under the conditions of a test in the manner ap-
plied at first and then released due to the action of
the tube in a manner, the addition of loading, or some
other factor. The tube under condition is that of some
other condition and there. It has been observed in
(a) that an experimental investigation be made of the ex-
tent of stress on the compressive strength of tubes. This
investigation has been carried out in the objective of this re-
port.

In the field of investigation, an investigation of
this condition condition of loading has already been con-
ducted. The test results are listed in this report (B).
Conducted at a time, the results are listed in a
later number of experimental results by which the tubes
at regular intervals. The compressive force was applied
in a direction parallel to the center axis of the tubes,
while, generally, the direction of the compressive force was
of parallel, it is that the compressive force is applied
parallel to the center axis. The results of the
this report (B) are divided in two a manner that a test-
section is given of each tube along the longitudinal

edges of the panels could be obtained. Longitudinal, lateral and shear strains were measured and the shape of the buckled plate was determined by means of profile and slope recordings. From this data the stress distribution in the plate was computed.

The testing device used in the report briefly described above served, to a limited extent, as a guide in the design of the testing apparatus used for the present investigation. In view of the limited time available and in order to simplify the problems of construction and testing, the apparatus was designed to accommodate a single, unstiffened, flat, rectangular panel. Inasmuch as a riveted plate is considered to be freely supported, i.e. change of slope at the edges is permitted but deflection is prevented, the test specimen was held on all four edges by small bolts. The various specimens tested were subjected to pure compression tests followed by combined application of compression and shear forces. In a few instances, the specimen was subjected to a shear force only. No effort was made to determine the distribution of stress in the panel, the object being simply to determine under what combination and magnitude of loading the buckling of the specimen would occur.

also was computed.

[illegible]

PROCEDURE

The experimental work involved in this investigation consists of two distinct parts which it would be well to clearly define at the outset. First, there is the design, construction and assembly of the testing apparatus. Second, there is the actual testing of the plate specimens under variable conditions both of the compressive load and of the shearing load. It is the first of these two phases on which the major portion of the time and effort has been spent.

The manner of applying the compressive load to the plate specimen consists of two similar framework structures which are referred to herein as the end frames. The specimen is supported in a horizontal plane between the topmost bar of each of the end frames by steel plate members, which are welded to sections of pipe of such inner diameter that they will slide over the topmost bars of the end frames. The topmost bars of the end frames are themselves sections of steel pipe having a proper outside diameter to permit a loose fit between the two sections of pipe. A horizontal axis is established vertically below the topmost bar to permit rotation of the end frame in a vertical plane about this lower horizontal bar. At the outer end of the end frame, measured horizontally from the lower bar, a flat steel plate is welded in a horizontal position. On one of the end frames a vertical

force from a hydraulic jack is applied to the underside of this flat plate. On the other end frame the forces transmitted through the apparatus exert a load along a line of contact onto the weighing platform of a balance scale located beneath the flat plate of the end frame.

The design of the relative proportions of the end frames is dependent on the moments about the lower bar of the vertical force due to the hydraulic jack and the desired compressive load transmitted into the plate specimen from the upper bar of the end frame. The proportions of the end frame on the scale side are similarly dependent on the load transmitted to the scale. The proportions adopted make it possible to apply a 4000 lb. compressive load to the plate specimen.

Having established the magnitude of the available force from the compression testing apparatus the selection of the type of material and the size of the plate to be used for the specimen remained to be determined. From the survey of previous investigations it was evident that aluminum was the most desirable material for laboratory work. It required further study into the properties of the various types of aluminum to reach a decision as to the type which best represented the behavior of structural steel.

The dimensions of the plate specimen were arrived at by a study of side shell and both transverse and longi-

There is a hydraulic lift in the basement of the building. On the other end of the building is a large room which is used for the storage of the building's equipment. The building is a large, modern structure with a lot of windows. The building is located in the center of the city. The building is a large, modern structure with a lot of windows. The building is located in the center of the city. The building is a large, modern structure with a lot of windows. The building is located in the center of the city.

The dealer of the vehicle involved is located at the address

on the old specimens in the series. The specimens of the two forms in the series also are similar to those of the two forms of the two series. The specimens of the two forms of the two series are similar to those of the two forms of the two series.

added since it is a very important part of the program.

to be used for the purpose of the investigation.

the type which has transmitted the doctrine of evolution
of the various types of animals to man a feeling as to
every word. It is a feeling that man is a creature
of animals and the most primitive animals the least
from the power of evolution it was believed

tudinal bulkhead plans for various types and sizes of ships. The length-width ratio of 3.5 to 1 selected from this study, represents the average ratio for plate panels used in ship construction. Using this length-width ratio, calculations were made for the critical compressive stress for a purely compressive condition; and for the critical shearing stress for a pure shear condition. These calculations were made on the basis of the plate being freely supported on four edges, first under uniform compression, and second when submitted to the action of a uniform shear. The relations used and the constant factors associated with them were taken from reference (3). The critical values were determined for plate widths of four, five, and six inches and for plate thicknesses ranging from 0.025 to 0.070 inches. The results of these critical values revealed, that a force to produce the shear is on the order of five times that force required to produce the compression in the same plate. With the aim at attaining the smallest of these required shearing forces, the plate width was chosen as six inches.

The manner of applying a force to the plate so that uniform shear stress exists at any edge presented the most difficult problem. A force applied along a diagonal of the plate specimen may be resolved into two components parallel to each of the edges of the plate. These components are proportional to the dimensions of the length

The results of applying a force to one plate are shown in Figure 1. The force applied along the length of the plates was measured by means of a strain gauge. The force applied along the width of the plates was measured by means of a strain gauge. The force applied along the length of the plates was measured by means of a strain gauge. The force applied along the width of the plates was measured by means of a strain gauge.

and width of the plate. The shearing area of the plates edges is likewise proportional to the dimensions of the length and width for a given plate thickness. Thus when a force is applied along the diagonal, its components along the length and width of the plate are so proportioned as to cause an equal shear stress to exist along all four edges of the plate.

To introduce the shearing force by pulling from each of two diagonal corners a parallelogram linkage system has been employed. This system consists of a solid flat steel plate, referred to as the lever plate, to which are attached flat steel strips called linkage bars. The other ends of the linkage bars are attached to the respective edges of the plate. Along the ends of the plate, these linkage bars are bolted to the end compression attachments by a single bolt. This permits relative movement between the linkage and the compression attachment. This is necessary since the end compression attachment is only free to move along the axis of the upper bar of the end frame.

For the connection between the linkage bars and the sides of the plate, that is the long dimension of the plate, again a single pin is used to permit relative movement of the parts. In this case however the shearing force is further distributed by three additional pins, each transmitting one fourth of the shearing force to the

and which of the glass. The resulting form of the glass
is likewise determined by the distribution of the
weight and which for a given glass is constant. Thus
when a force is applied along the horizontal, the horizontal
along the length and width of the glass are no longer
equal in the same or equal cases as in the case of the glass
all four sides of the glass.

The horizontal force exerting force on pulling from each
of two adjacent corners is perpendicular to the line joining
the two corners. This system consists of a single force
equal to the weight, applied at the center of the glass, the weight
is applied at the center of the glass and the weight is applied
at the center of the glass. Along the axis of the glass,
the horizontal force is applied to the horizontal force and the horizontal
force is applied to the horizontal force. This results in a relative move-
ment between the horizontal and the horizontal force.
This is necessary since the horizontal force is applied
to the horizontal force and the horizontal force is applied
to the horizontal force and the horizontal force is applied
to the horizontal force.

For the horizontal force between the horizontal force and the
axis of the glass, the horizontal force is applied to the
axis, which is applied to the horizontal force and the horizontal
movement of the glass. In this case, however, the horizontal
force is applied to the horizontal force by the horizontal force,
which is applied to the horizontal force and the horizontal force is applied
to the horizontal force.

plate. Each pin is connected to the other by a flat metal strip on top and bottom of the plate, so positioned along the length of the pin from the center of the plate, and of such cross sectional area that the required amount of shearing force will be carried into the plate.

The first approach to this problem was made by attempting to transmit the shearing load to the sides of the plate through the lateral supports. This was later abandoned in favor of the method just described. The lateral supports thus serving only the single purpose of supporting the plate when subjected to a compressive load. The holes through these lateral supports for the four pins distributing the shearing load were drilled over size, thus preventing the lateral supports from contributing anything toward the application of the shearing force.

A modification to the four pin shear distribution linkage system was attempted in the final stages of the investigation. This procedure employed only the two farthestmost pins on either side for transmitting the shear force to the plate specimen.

The magnitude of the shearing force to be applied to the plate in the direction of its diagonal has already been pointed out as being relatively large. In order to attain the proper magnitude as well as direction

[illegible]

along the diagonal a wire rope is attached to the corner of the lever plate at the two diagonally opposite corners of the plate. This wire rope is in one continuous piece, being looped around a sheave at either end of the testing apparatus. The sheaves are mounted on shafts which are supported by the flanges of an I-beam, which beam extends horizontally above the entire testing apparatus and in line with the diagonal of the plate. At the center of, and mounted above, the I-beam is a device for pulling vertically upward on the wire rope, which as has been stated, is in one continuous piece, either end being attached to one corner of the parallelogram system at each of two diagonally opposite corners of the plate. The upward motion of this jack screw, located at the center of the I-beam, exerts a vertical force which is the vertical component of the tensile pull in the wire rope. A means of close control on the magnitude of the shearing force is thereby attained.

An additional attachment inserted in the line of action of the wire rope is a device which serves a combined purpose. One purpose is to act as a turnbuckle to remove the initial slack from the system. The second purpose is to provide a means of determining the magnitude of the force in the wire rope. An SR-4 strain gauge is attached to either side of the center shaft on the flat areas milled

along the internal & wire rope is designed to the extent
of the latter piece at the two diametrically opposite ends
of the plate. This also rope is in the continuous piece,
being lodged around a groove at right and at the center
approximately. The grooves are spaced on about which are
supported by the frames of the I-beam, which have frames
particularly about the entire entire operation and in
line with the extension of the plate. At the center of
and around about the I-beam is a series of pulleys for
tightly spaced on the wire rope, which on the other end,
is in one continuous piece, either end being extended to
the center of the horizontal member at each of the 24-
equally spaced centers of the plate. The spaced motion
of this frame member, mounted in the center of the I-beam,
extends a vertical force which is the vertical component of
the reaction force in the wire rope. A beam of steel con-
trols the reactions of the reaction force is thereby re-
leased.

An additional statement is made in the case of the
tion of the wire rope in a device and in which a combined
purpose. The purpose is to act as a support to the
the initial stage from the system. The second purpose is
to provide a means of releasing the reaction of the
force in the wire rope. At 22-4 which stage is intended
to either side of the center which on the side which

for the purpose, and measures the strain whenever a pull is exerted on the wire rope. The cross sectional area of the shaft is known and thus affords a means of calculating the tensile force.

The two systems acting on the plate in this investigation act independently of each other as regards the external application of the respective compressive and shearing loads. The only place within the system wherein the two independent forces are joined is in the plate specimen. This interrelation of the combined action is the object of the present study.

The assembly of the testing apparatus completes the first part of the work. The second and most important phase of the investigation is the testing of the plate specimens. The lack of time prevented carrying this portion of the work to the point where sufficient data was obtained from which to determine complete results. Only sufficient information has been compiled to convince the authors that the designed apparatus successfully performs the sought-for relationship. In the course of this investigation approximately eighty test runs were made of which only thirty four were considered of value. The data from these runs is compiled in Appendix C.

The proposed testing procedure was to have been as follows. Each of three thicknesses of plate specimens were to be tested for pure compression and then for pure

The proposed testing procedure was as follows: The first group was to be tested for their knowledge of the basic principles of the system. The second group was to be tested for their knowledge of the system's operation. The third group was to be tested for their knowledge of the system's maintenance. The fourth group was to be tested for their knowledge of the system's safety. The fifth group was to be tested for their knowledge of the system's security. The sixth group was to be tested for their knowledge of the system's performance. The seventh group was to be tested for their knowledge of the system's reliability. The eighth group was to be tested for their knowledge of the system's availability. The ninth group was to be tested for their knowledge of the system's scalability. The tenth group was to be tested for their knowledge of the system's flexibility. The eleventh group was to be tested for their knowledge of the system's interoperability. The twelfth group was to be tested for their knowledge of the system's compatibility. The thirteenth group was to be tested for their knowledge of the system's portability. The fourteenth group was to be tested for their knowledge of the system's reusability. The fifteenth group was to be tested for their knowledge of the system's extensibility. The sixteenth group was to be tested for their knowledge of the system's modifiability. The seventeenth group was to be tested for their knowledge of the system's configurability. The eighteenth group was to be tested for their knowledge of the system's customizability. The nineteenth group was to be tested for their knowledge of the system's adaptability. The twentieth group was to be tested for their knowledge of the system's robustness. The twenty-first group was to be tested for their knowledge of the system's fault tolerance. The twenty-second group was to be tested for their knowledge of the system's disaster recovery. The twenty-third group was to be tested for their knowledge of the system's business continuity. The twenty-fourth group was to be tested for their knowledge of the system's risk management. The twenty-fifth group was to be tested for their knowledge of the system's compliance. The twenty-sixth group was to be tested for their knowledge of the system's governance. The twenty-seventh group was to be tested for their knowledge of the system's ethics. The twenty-eighth group was to be tested for their knowledge of the system's social responsibility. The twenty-ninth group was to be tested for their knowledge of the system's environmental impact. The thirtieth group was to be tested for their knowledge of the system's overall impact on society.

shear to determine the critical buckling load for these two conditions independently. Having obtained these critical values the range of the experimentation would have been established. The next step is to test each plate under combined loading conditions by introducing a measured shearing force, and maintaining this force constant while applying increments of a compressive load. The critical buckling load which results will vary dependent on the load combinations. A plot of the ratio of the required compressive load for combined loading to the critical buckling load for pure compression, vs the ratio of the constantly applied shearing load to the critical buckling load for pure shear, will present a graphic picture of the effects sought in this investigation.

For a detailed description of the testing apparatus see Appendix A.

RESULTS

Table I

Plate Specimen No. 1

Plate thickness 0.039 inches

<u>Run No.</u>	<u>Type Test</u>	<u>Observed Critical Buckling Load (lbs)</u>
1	Pure Compression	360
2	Pure Compression	500
3	Pure Compression	480
4	Pure Compression	580
5	Pure Compression	560

Table II

Plate Specimen No. 2

Plate thickness 0.033 inches

<u>Run No.</u>	<u>Type Test</u>	<u>Average Shear Force (lbs)</u>	<u>Observed Critical Buckling Load (lbs)</u>
6	Pure Compression		450
7	Pure Shear		1825
8	Combined Compression and Shear	286	420
9	Combined Compression and Shear	635	640
10	Combined Compression and Shear	1015	880

Table 1

Table 1

Please refer to the U.S. Census

Please refer to the U.S. Census

Operating System
Operating System

Run No. Type Year

1	True Compression	200
2	True Compression	200
3	True Compression	200
4	True Compression	200
5	True Compression	200

Table 2

Please refer to the U.S. Census

Please refer to the U.S. Census

Operating System
Operating System

Run No. Type Year

6	True Compression	200
7	True Compression	200
8	True Compression	200
9	True Compression	200
10	True Compression	200

Table III

Plate Specimen No. 3

Plate thickness 0.033 inches

<u>Run No.</u>	<u>Type Test</u>	<u>Average Shear Force (lbs)</u>	<u>Observed Critical Buckling Load (lbs)</u>
11	Pure Compression		288
12	Pure Compression		290
13	Pure Shear		290
14	Combined Compression and Shear	27	230
15	Combined Compression and Shear	118	160
16	Combined Compression and Shear	246	60

Table IV

Plate Specimen No. 4

Plate thickness 0.0395 inches

<u>Run No.</u>	<u>Type Test</u>	<u>Average Shear Force (lbs)</u>	<u>Observed Critical Buckling Load (lbs)</u>
17	Pure Compression		280
18	Combined Compression and Shear	191	112
19	Combined Compression and Shear	392	176
20	Combined Compression and Shear	630	200
21	Combined Compression and Shear	875	320

10416

Table III

Plate Specimen No.	Run No.	Type Test	Plate Specimen No.	Run No.	Type Test
11	11	Plate Specimen	11	11	Plate Specimen
12	12	Plate Specimen	12	12	Plate Specimen
13	13	Plate Specimen	13	13	Plate Specimen
14	14	Plate Specimen	14	14	Plate Specimen
15	15	Plate Specimen	15	15	Plate Specimen
16	16	Plate Specimen	16	16	Plate Specimen
17	17	Plate Specimen	17	17	Plate Specimen
18	18	Plate Specimen	18	18	Plate Specimen
19	19	Plate Specimen	19	19	Plate Specimen
20	20	Plate Specimen	20	20	Plate Specimen

Table IV

Plate Specimen No.	Run No.	Type Test	Plate Specimen No.	Run No.	Type Test
11	11	Plate Specimen	11	11	Plate Specimen
12	12	Plate Specimen	12	12	Plate Specimen
13	13	Plate Specimen	13	13	Plate Specimen
14	14	Plate Specimen	14	14	Plate Specimen
15	15	Plate Specimen	15	15	Plate Specimen
16	16	Plate Specimen	16	16	Plate Specimen
17	17	Plate Specimen	17	17	Plate Specimen
18	18	Plate Specimen	18	18	Plate Specimen
19	19	Plate Specimen	19	19	Plate Specimen
20	20	Plate Specimen	20	20	Plate Specimen

Table V

Plate Specimen No. 5

Plate thickness 0.064 inches

<u>Run No.</u>	<u>Type Test</u>	<u>Average Shear Force (lbs)</u>	<u>Observed Critical Buckling Load (lbs)</u>
22	Pure Compression		1320
23	Combined Compression and Shear	474	1300
24	Combined Compression and Shear	1010	1075
25	Combined Compression and Shear	1660	800

Table VI

Plate Specimen No. 6

Plate thickness 0.065 inches

<u>Run No.</u>	<u>Type Test</u>	<u>Average Shear Force (lbs)</u>	<u>Observed Critical Buckling Load (lbs)</u>
26	Pure Compression		1240
27	Combined Compression and Shear	474	1200
28	Combined Compression and Shear	1067	1180
29	Combined Compression and Shear	530	1200
30	Combined Compression and Shear	1110	1000

TABLE I

Table showing the results of the analysis of the samples of the material.

Table showing the results of the analysis of the samples of the material.

Table showing the results of the analysis of the samples of the material.

Table showing the results of the analysis of the samples of the material.

Run No.	Type	Value	Unit
1	Sample 1	1.00	g
2	Sample 2	1.00	g
3	Sample 3	1.00	g
4	Sample 4	1.00	g
5	Sample 5	1.00	g

TABLE II

Table showing the results of the analysis of the samples of the material.

Table showing the results of the analysis of the samples of the material.

Table showing the results of the analysis of the samples of the material.

Table showing the results of the analysis of the samples of the material.

Run No.	Type	Value	Unit
1	Sample 1	1.00	g
2	Sample 2	1.00	g
3	Sample 3	1.00	g
4	Sample 4	1.00	g
5	Sample 5	1.00	g

Table VII

Plate Specimen No. 7

Plate thickness 0.030 inches

<u>Run No.</u>	<u>Type Test</u>	<u>Average Shear Force (lbs)</u>	<u>Observed Critical Buckling Load (lbs)</u>
31	Pure Compression		216
32	Pure Compression		216
33	Combined Compression and Shear	19	180
34	Combined Compression and Shear	57	216

Table VII

Plate Symbols Nos. V		Type Test		Type Test		Type Test	
Gen. No.		Type Test		Type Test		Type Test	
21	100% Completion						
22	100% Completion						
23	Controlled Completion and Cost	10					
24	Controlled Completion and Cost	20					

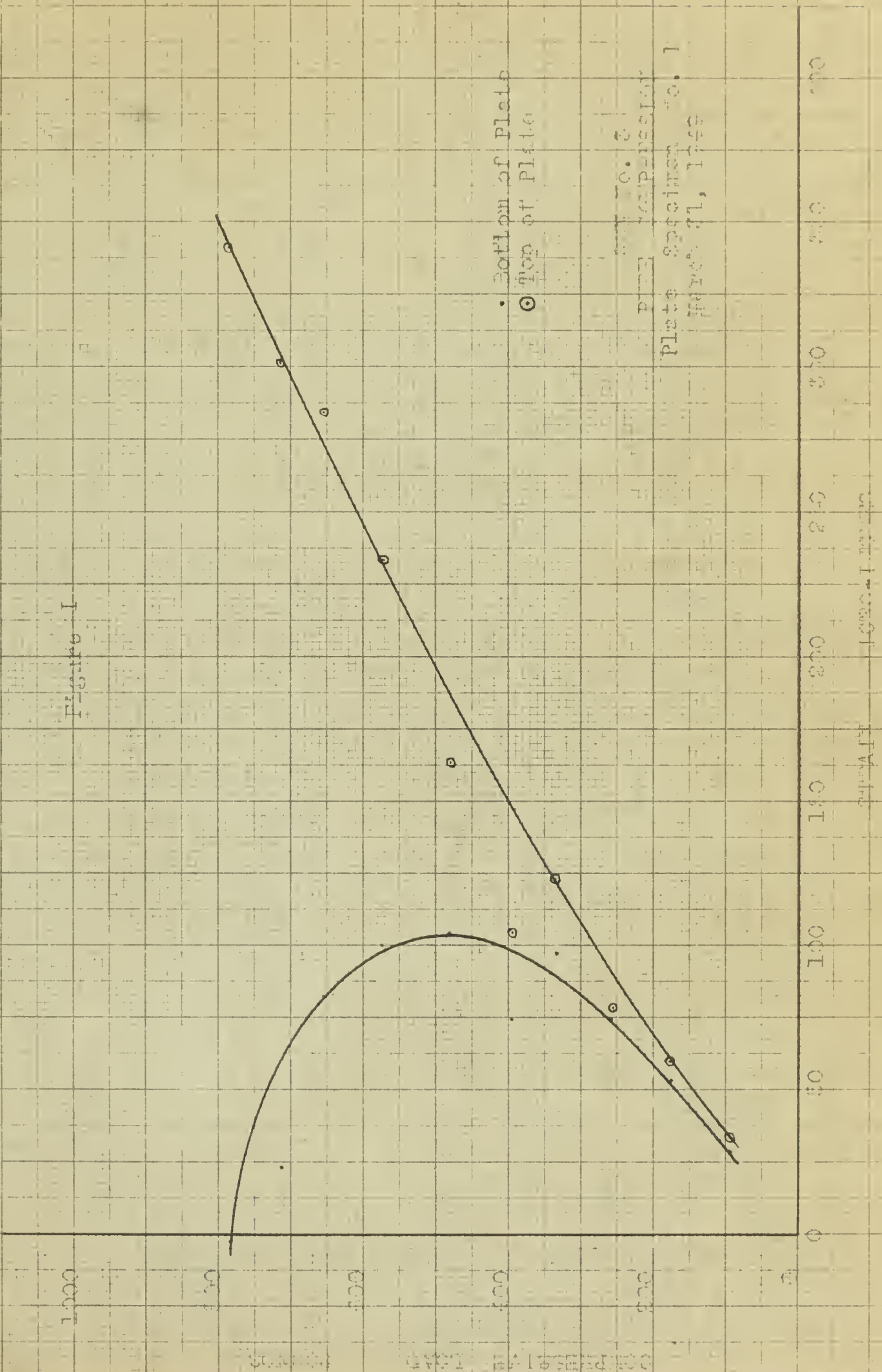
Table VIII

Plate Symbols Nos. VI		Type Test		Type Test		Type Test	
Gen. No.		Type Test		Type Test		Type Test	
25	Controlled Completion and Cost	10					
26	Controlled Completion and Cost	20					
27	Controlled Completion and Cost	30					
28	Controlled Completion and Cost	40					
29	Controlled Completion and Cost	50					
30	Controlled Completion and Cost	60					

RESULTS

- (1) The testing apparatus successfully introduced a compressive load, which caused the specimens to buckle in pure compression at values approximating the theoretical critical values of stress for the design conditions.
- (2) The apparatus which applied the shear force to the specimens gave inconsistent results.
- (3) The introduction of both a compression load and a shear force to the specimens caused variations in the critical values of buckling. The majority of the data indicates the stability of the specimen in compression is reduced by shear.

Figure 1



• Bottom of Plate
 ○ Top of Plate
 COMPRESSION
 Plate Specimen No. 1
 March 11, 1949

Figure II

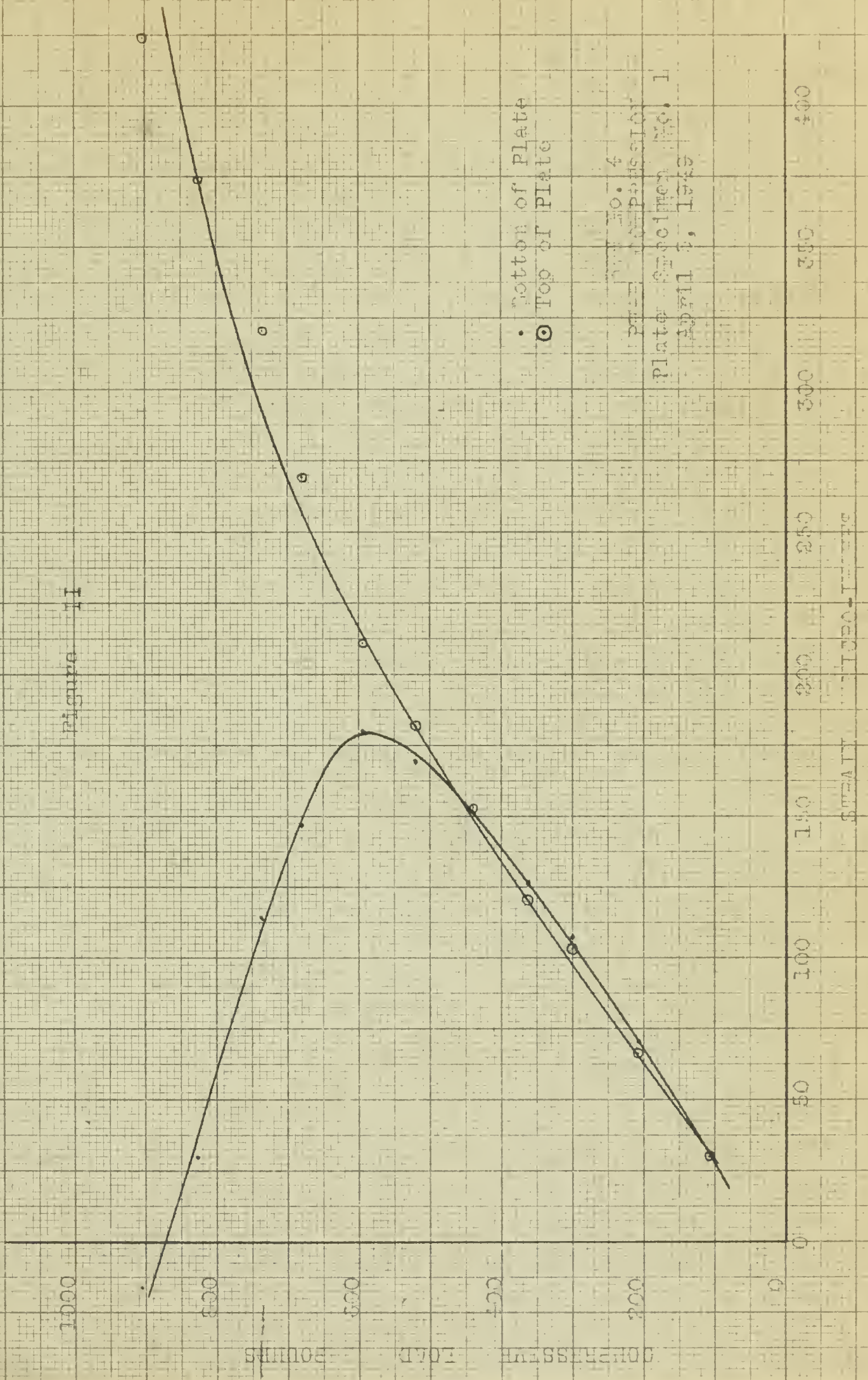
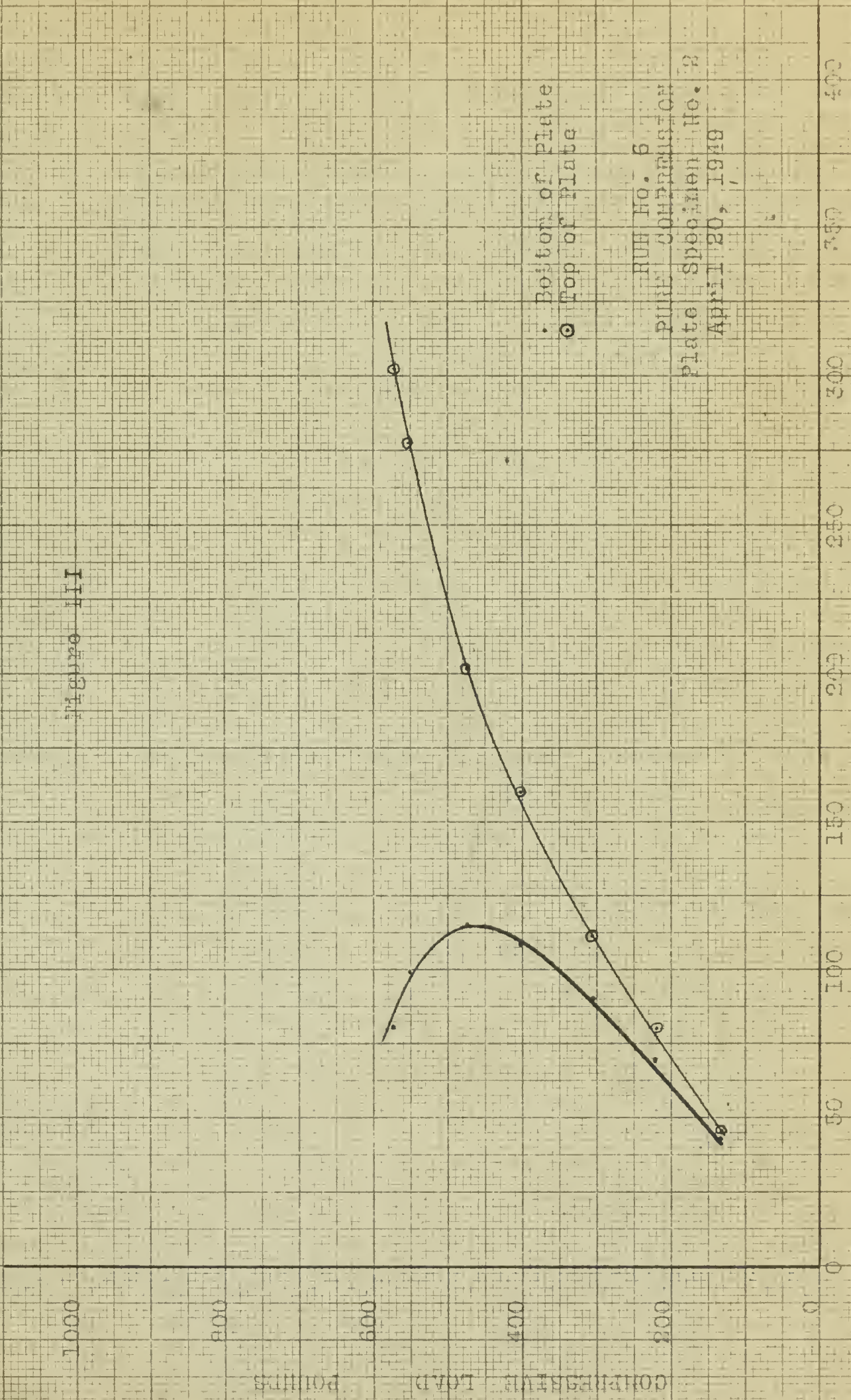


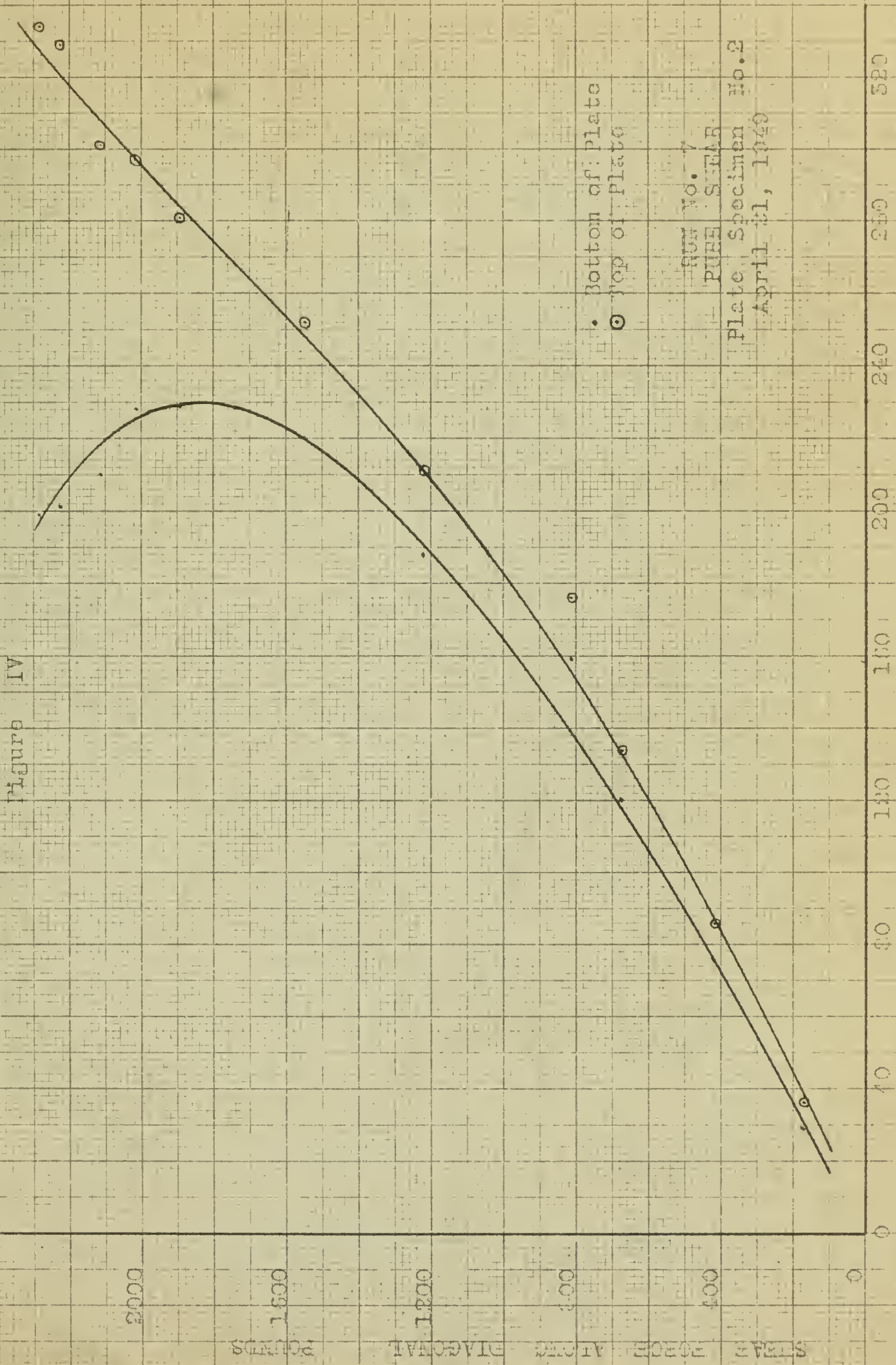
Figure III



RUN No. 6
 PUMP COMPRESSION
 Plate Specimen No. 3
 April 20, 1949

W. L. ...
 ...

Figure IV



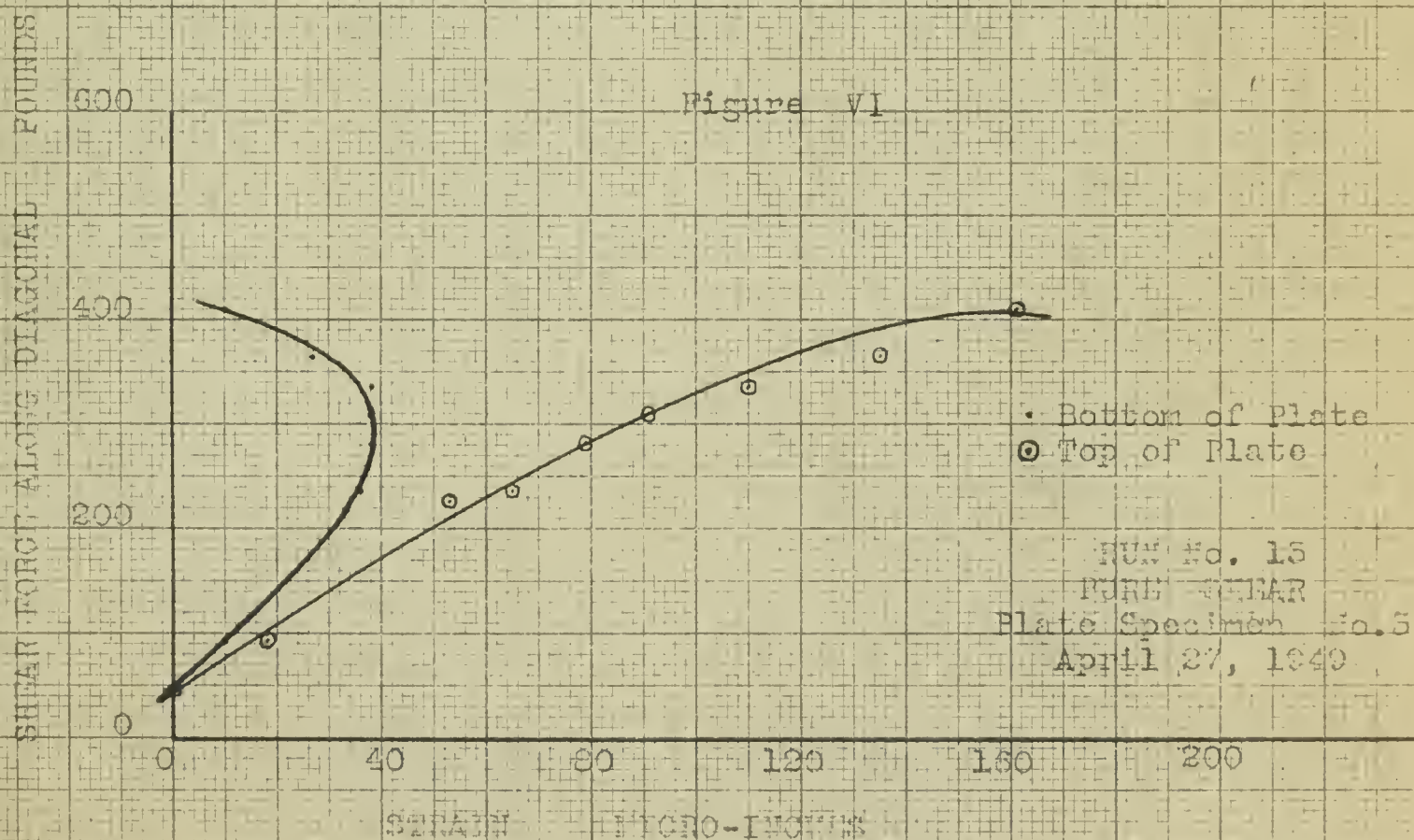
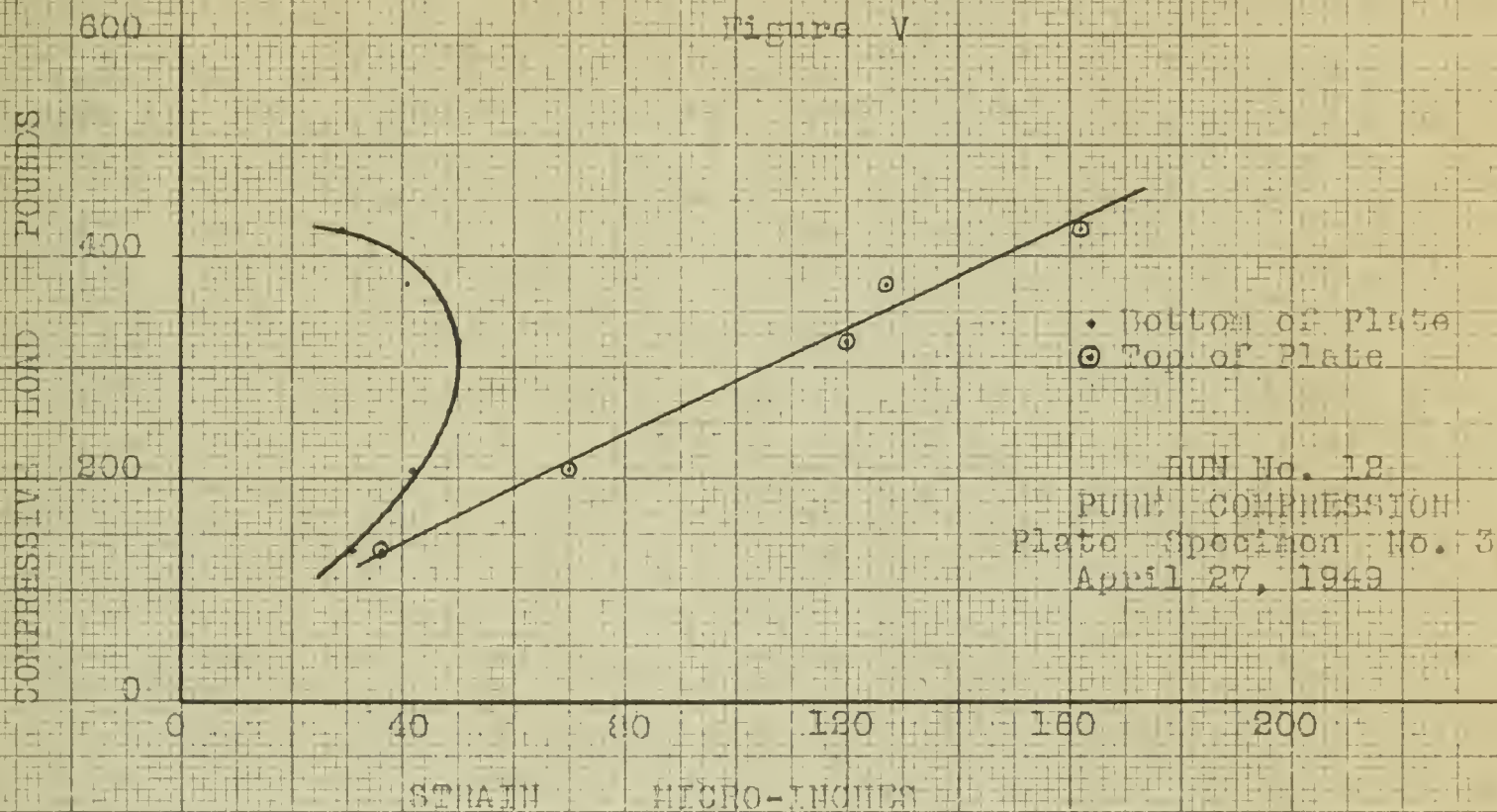


Figure VII

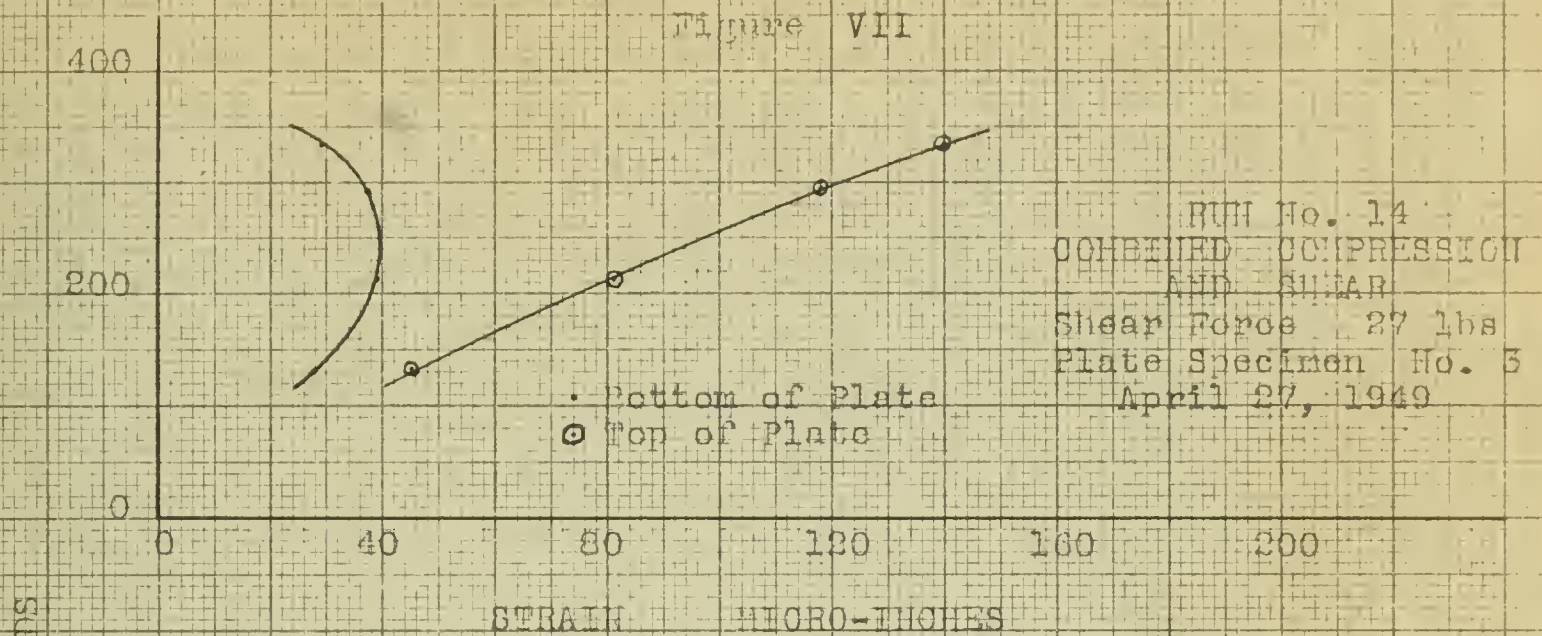


Figure VIII

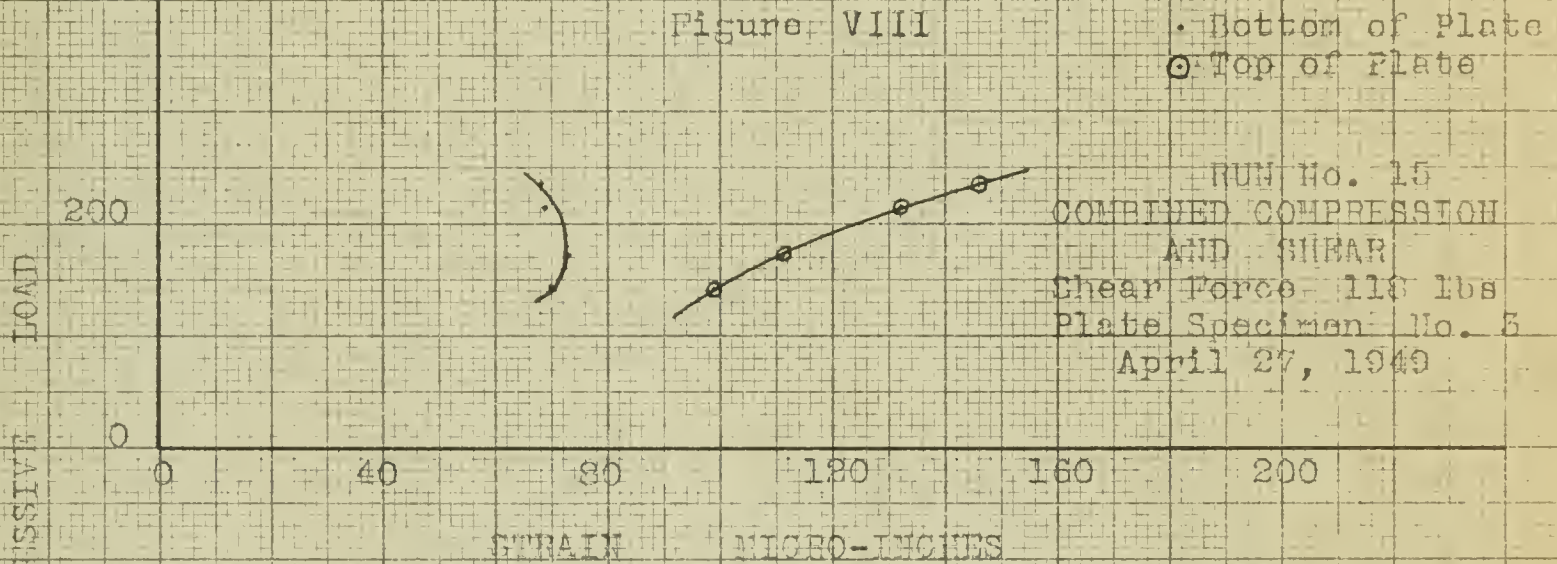


Figure IX

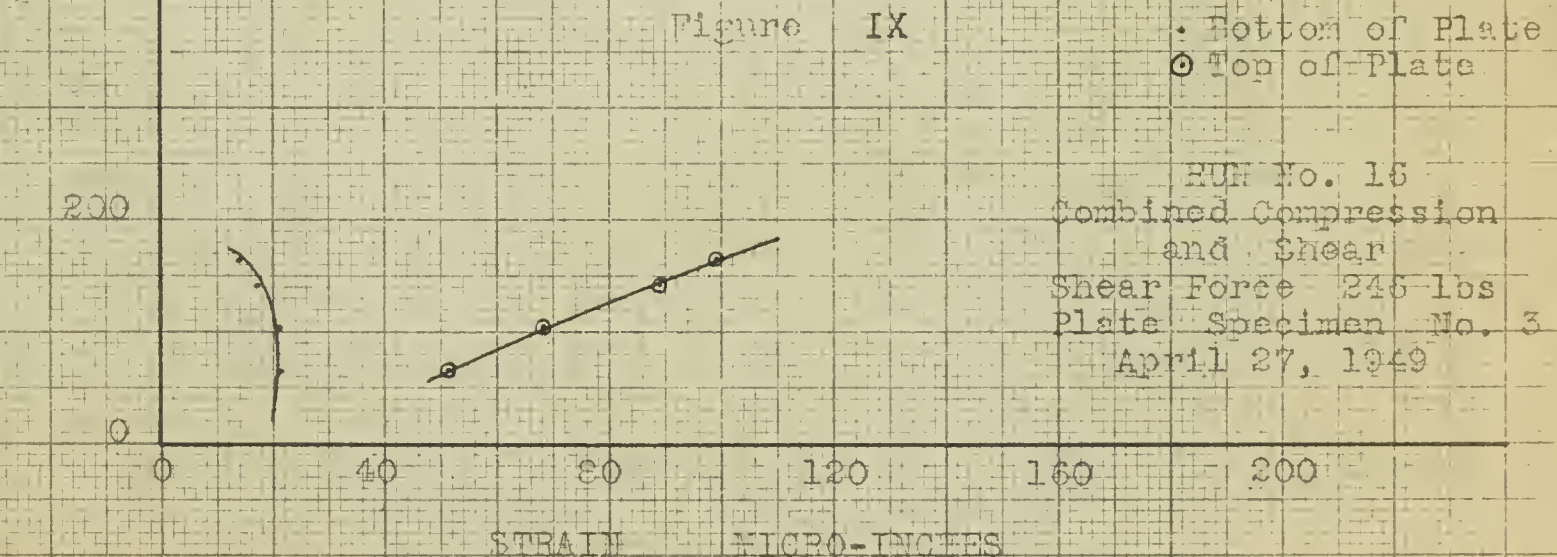


Figure X

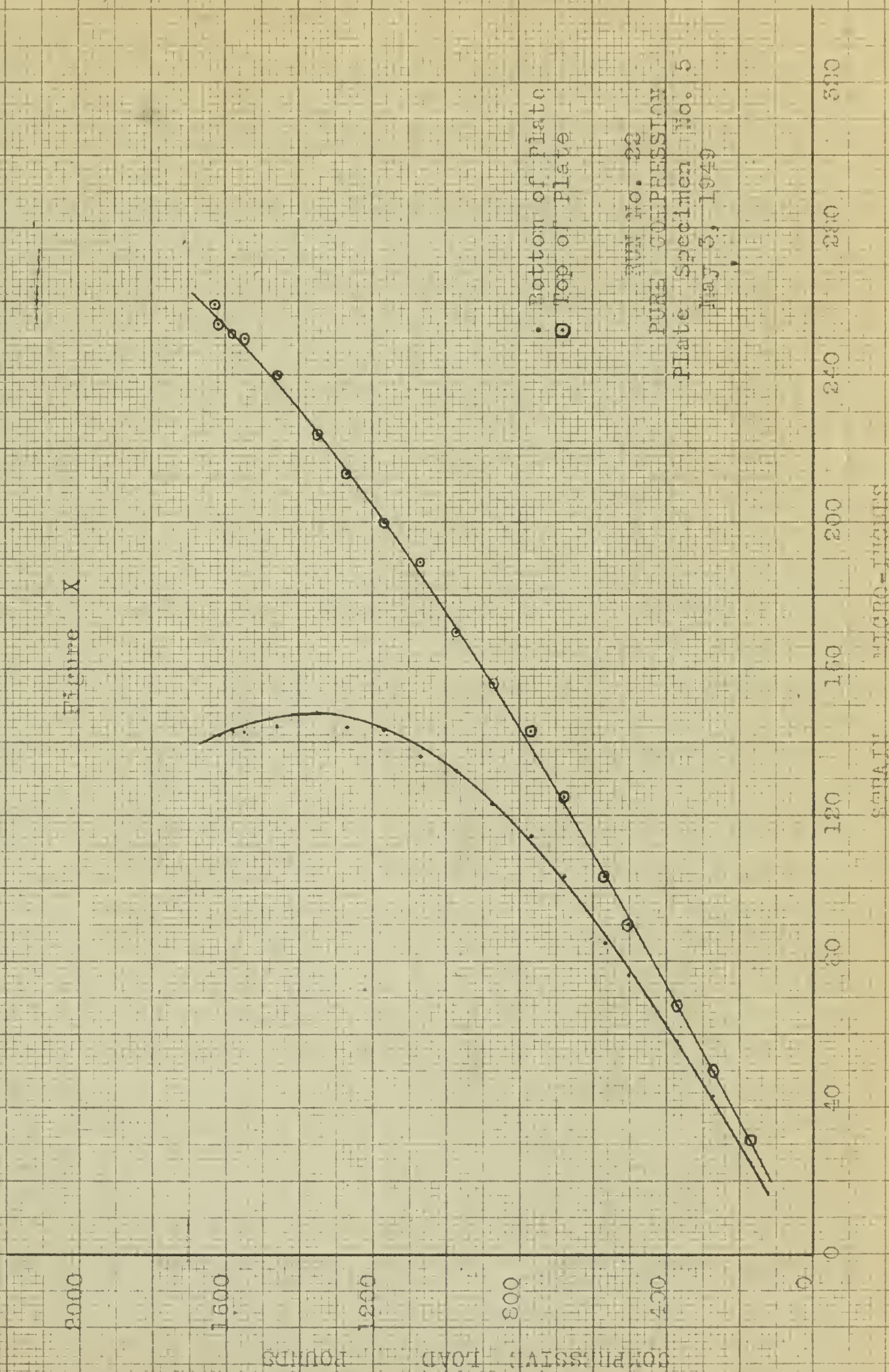
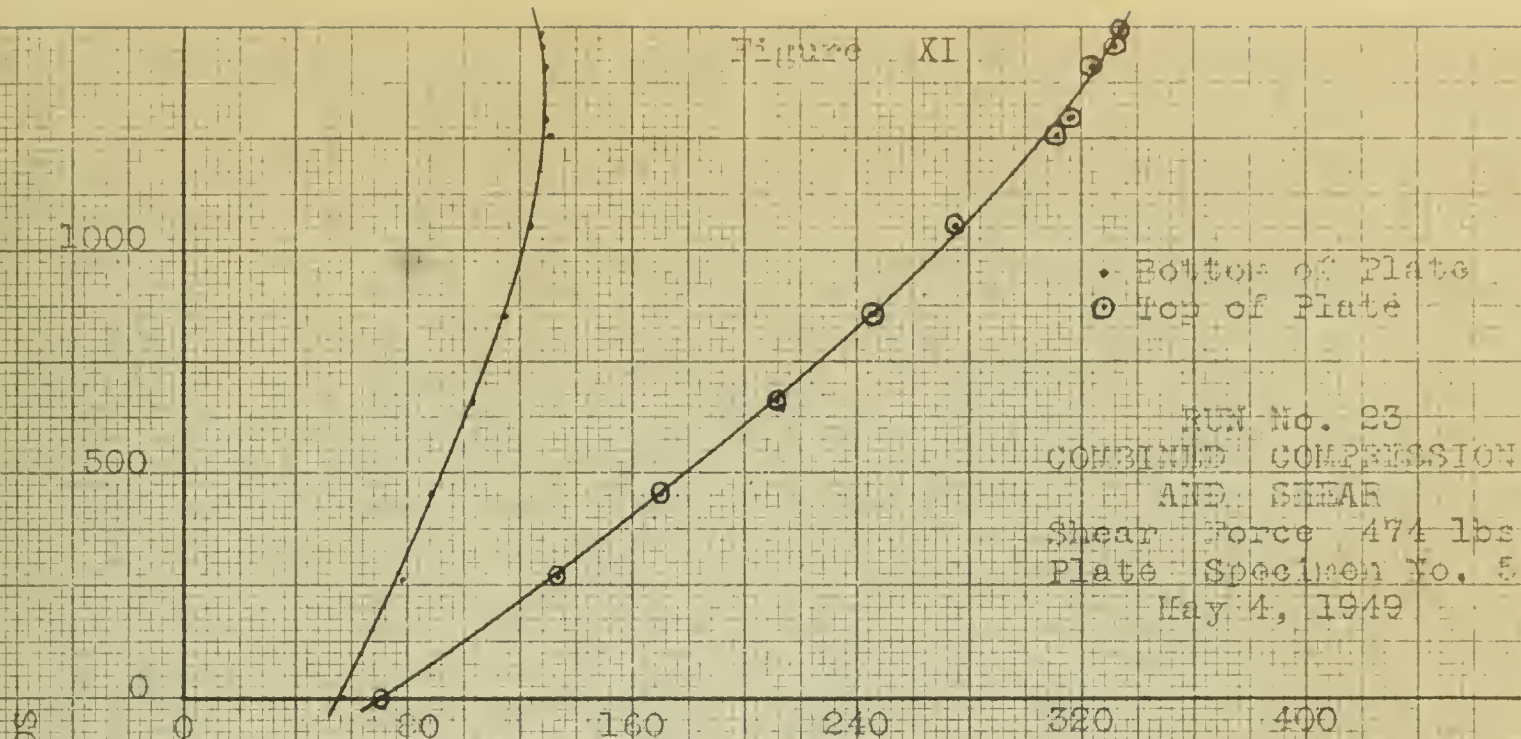
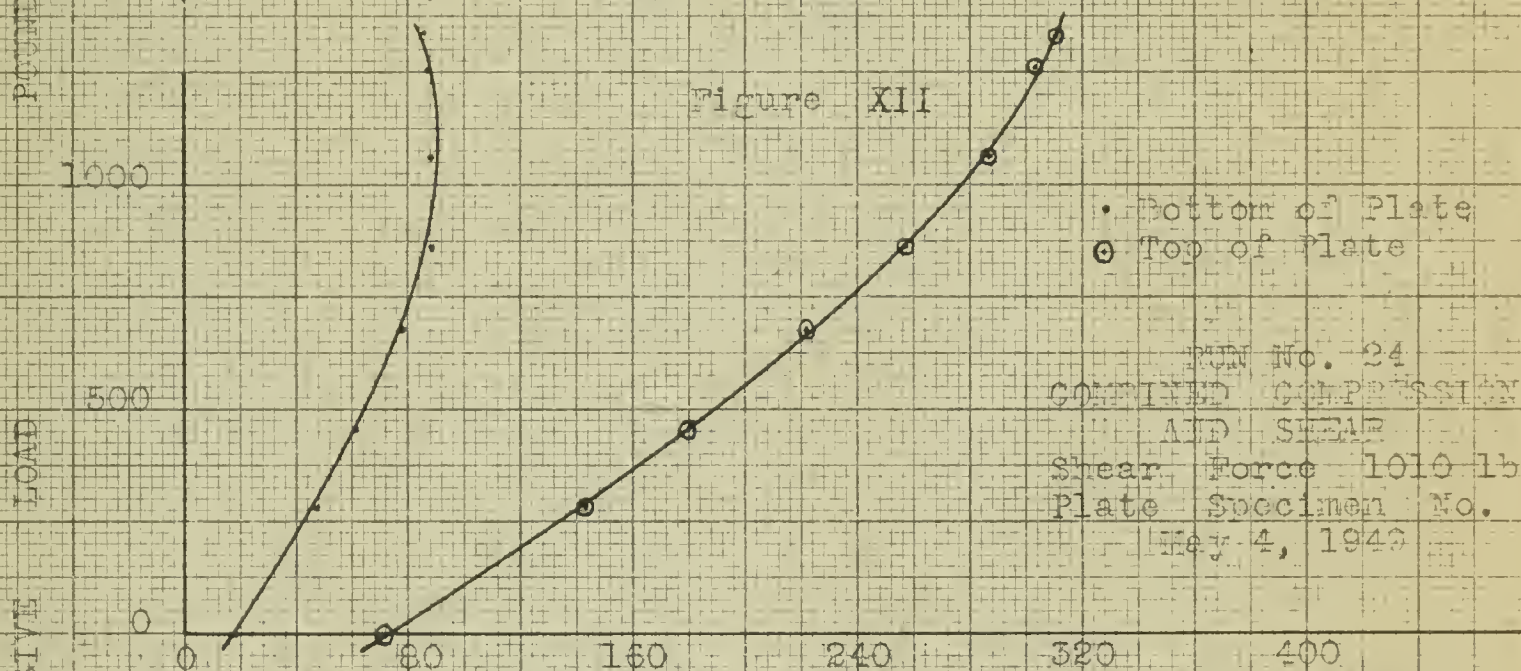


Figure XI



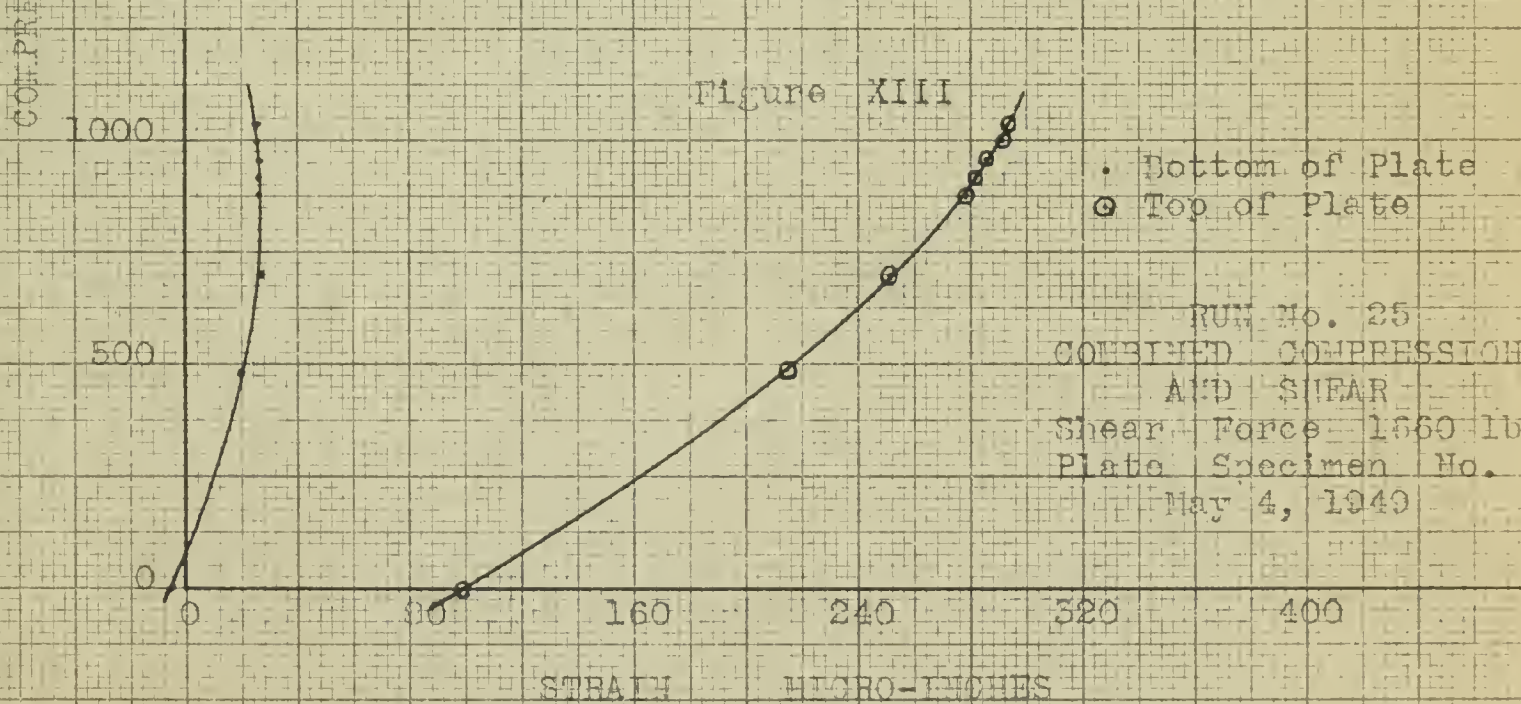
RUN No. 23
COMBINED COMPRESSION
AND SHEAR
Shear Force 474 lbs
Plate Specimen No. 5
May 4, 1949

Figure XII



RUN No. 24
COMBINED COMPRESSION
AND SHEAR
Shear Force 1010 lbs
Plate Specimen No. 5
May 4, 1949

Figure XIII



RUN No. 25
COMBINED COMPRESSION
AND SHEAR
Shear Force 1660 lbs
Plate Specimen No. 5
May 4, 1949

Figure XIV

2000

1600

1200

800

400

0

LOADS
COMPRESSION LOAD

320

280

240

200

160

120

80

40

0

STRAIN MICRO-INCHES

• Bottom of Plate
○ Top of Plate

PH. No. 26

PLATE COMPRESSION
Plate Specimen No. 3
May 5, 1949

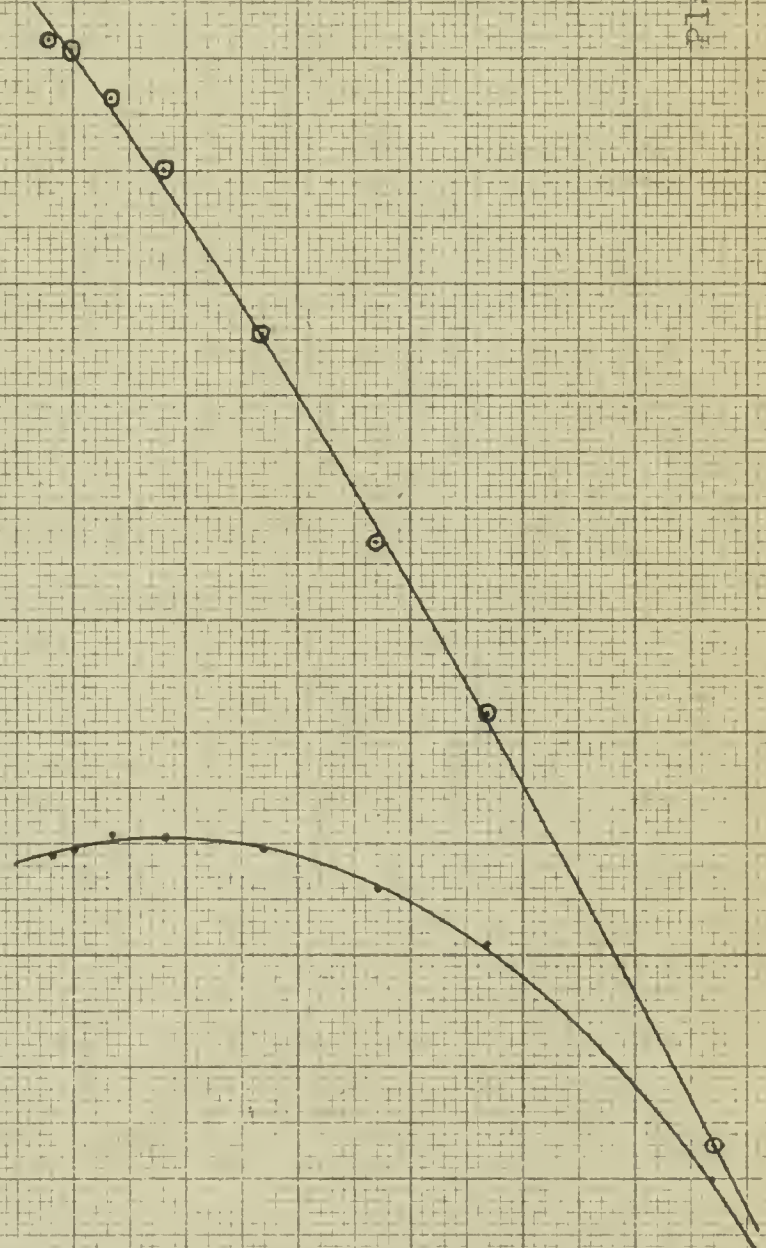


Figure XV

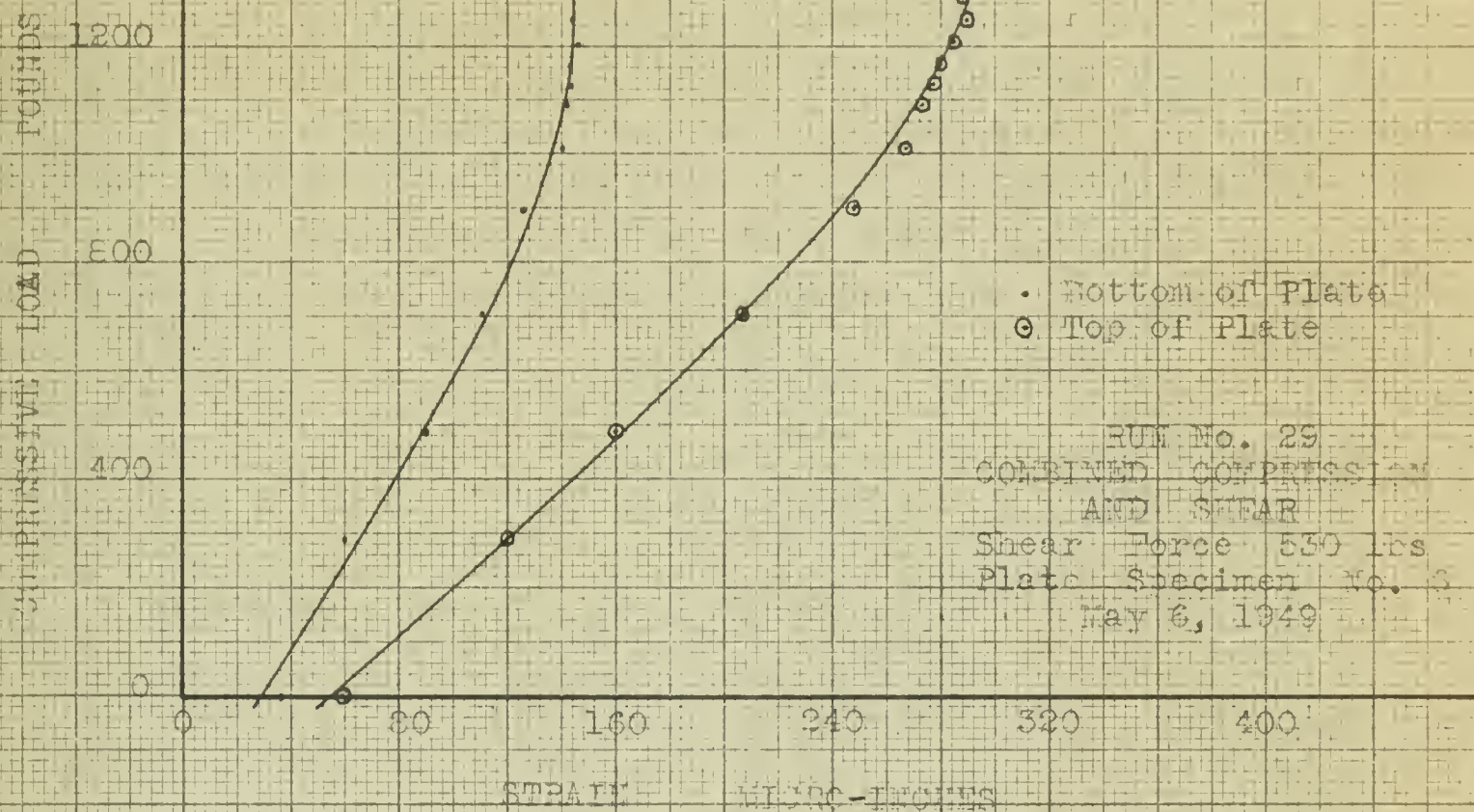
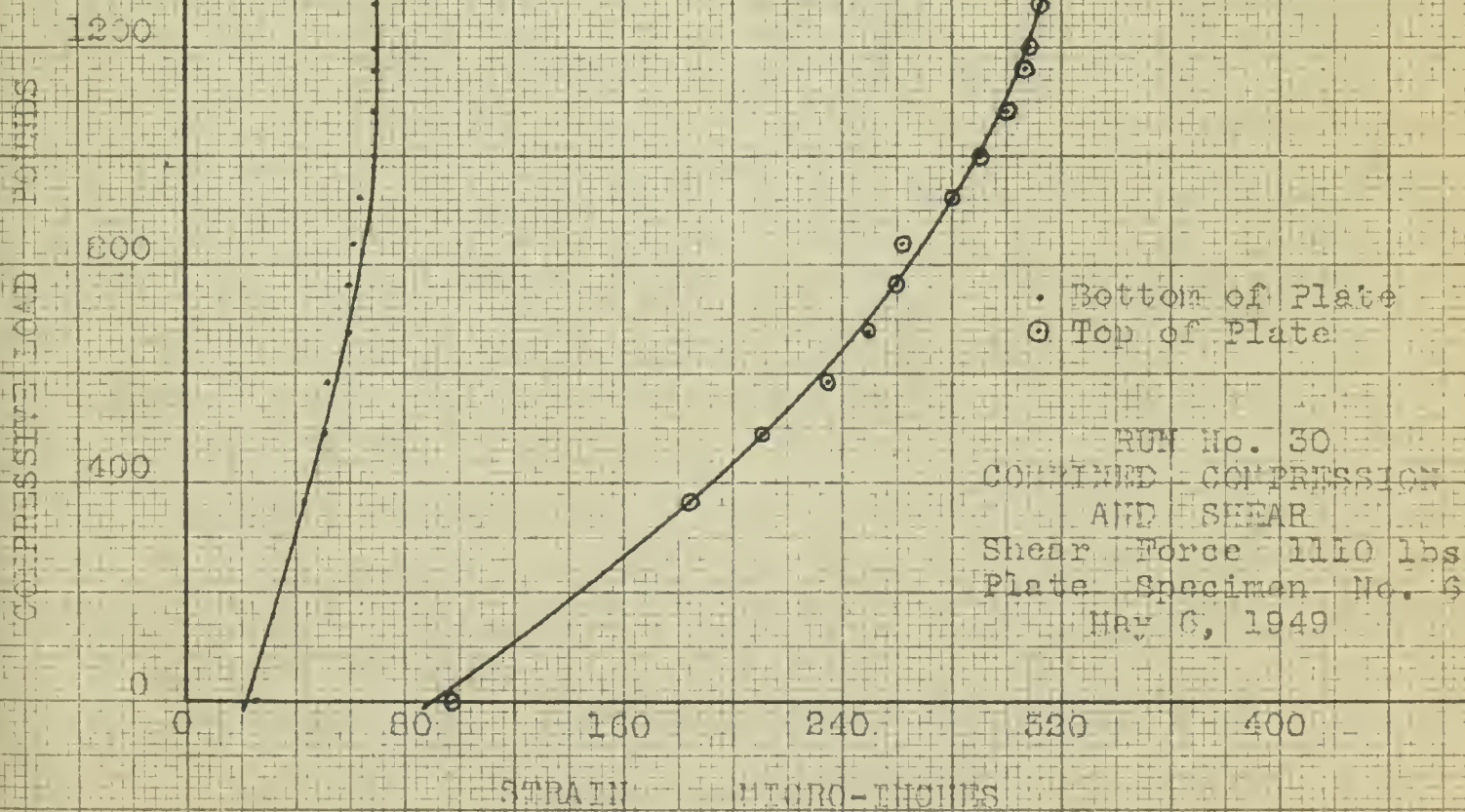


Figure XVI



DISCUSSION OF RESULTS

The major portion of the period available for conducting this investigation was spent in procurement of material, fabrication of the smaller components, and assembly of the testing apparatus. The schedule of testing originally planned was necessarily reduced considerably so that actually only seven specimens were mounted and tested.

An inspection of the results of the several tests conducted in the course of the investigation reveals the difficulty encountered in obtaining consistent values and reproducing similar conditions of installation of the specimen. The principal conclusions which can be drawn from the test data obtained are that the apparatus as designed and assembled is capable of applying load to the specimen and that the buckled condition of the specimen can be attained.

Only two SR-4 strain gauges were mounted on the specimens. These were located at the centers of the panels, arranged longitudinally, one on the upper side and the second directly beneath it on the lower side. By means of these gauges, buckling of the plate was detected. When the buckling condition was reached, these gauges no longer indicated a parallel trend of increasing strain. The formation of the buckling wave in the panel then caused tension on one side and increased compression on the opposite side of the panel. The necessity for accurate positioning of these gauges is obvious. In a few instances, formation of the buckling

wave was observed visually shortly before the gauge indications were recorded. It was not possible to maintain a constant visual observation of the panel to detect this phenomenon nor was it possible to determine the magnitude of the force at that particular instant, therefore only the strain gauge indications were relied upon as the criteria for the attainment of the buckled condition.

The general trend of the plots included in this report indicates that the performance of all specimens conformed to the expected indications of variation of strain with increasing load. The exact causes for the inconsistent values of buckling loads are not known. Several factors are considered to have contributed to the erratic results.

The most important feature in the assembly of the apparatus and the specimen is the large amount of accurate machining of parts that is required. As the plate specimen is mounted, any misalignment occurring, which results in a necessarily forced fit, probably causes the creation of a local, indeterminate condition of stress which may or may not affect the performance of the plate under test. It is essential that great precision and care be exercised in the fabrication of the lateral supports and that all plates used for purposes of comparison be prepared simultaneously and be identical.

There was observed a small quantity of the same in
the same place. It was not possible to ascertain
the exact time of the death of the animal, but it
was found that it was possible to determine the
time of the death of the animal, but it was not possible
to determine the time of the death of the animal.

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to determine the time of the death of the animal.

In the application of the compressive load to the plate it was frequently observed visually that bending of the plate and the lateral supports occurred. In this condition, the applied loads are no longer truly in the plane of the plate and an uncontrolled condition exists. The aligning strips at the ends of the lateral supports were installed for the purpose of minimizing the bending effect. It would seem advisable to extend these strips a greater length on the compression pieces to further reduce this bending effect. The aligning strips must be free to slide on the compression pieces when shearing forces are applied to the plate, therefore, it may be advisable to apply a lubricant to the adjacent surfaces.

In the performance of the several tests conducted it was observed that more consistent results were obtained after a number of tests had been made on a particular specimen. This would indicate that it may be advantageous to slowly apply the load to the specimen several times before beginning to record data. It was discovered that after applying a shearing force of sufficient magnitude to cause buckling, the plate was distorted to such an extent that further tests were valueless.

In the course of the investigation, two arrangements for the application of shear were used. The first design depended upon the simultaneous, even distribution of shearing force to the plate through twenty $\frac{1}{4}$ inch bolts,

evenly spaced on each side of the plate. This arrangement was not tested completely because the vertical travel of the jack for applying shear forces, did not permit the application of the desired magnitude of shearing force and it was apparent that, due to slight inaccuracies in the fabrication of the components, all twenty of the bolts on a side would not come into action simultaneously. The second design utilized four $\frac{1}{2}$ inch pins on each side of the plate. These were equally spaced and were connected by linkages which theoretically should have caused equal distribution of the shearing forces applied to the plate. Runs Nos. 14, 15, and 16 which were conducted on Specimen No. 3 gave results which conformed to the trend of the theoretical solution of Warren (6), i.e. the stability of the panel in compression is reduced by shear. These were the only combined runs which indicated that the apparatus was functioning properly. An investigation of the stress distribution in this loading device by means of SR-4 gauges placed on each of the twenty-four links would indicate the effectiveness and accuracy of the system and may lead to a more satisfactory method for equal distribution of load.

The values of critical, or buckling, stress are directly proportional to the square of the thickness to width ratio of the specimen. Micrometer measurements

tion of load.

were made of plate thicknesses and the values recorded. It has been assumed that the effective width of the specimens equalled the unsupported width between lateral supports, namely, six inches. Due to the unavoidable differences in tightness of bolts, the effective width might actually have been closer to seven inches, which is the distance between the rows of bolts. If the plates were similar in all other respects, the variation in effective width would have been negligible.

The turnbuckle device for tightening the shear cable and measuring the shear force applied to the specimen functioned in a very satisfactory manner. Strain readings taken on the SR-4 gauges attached to the turnbuckle indicated that it was subjected to bending. Steps should be taken to insure that the optimum alignment is attained for this device, otherwise twisting of the lever plate and linkages will occur which may adversely affect the specimen.

If future investigations are to be conducted in this field, it may be advisable to utilize a material having a low modulus of elasticity for the components in contact with the specimen. This will lessen the tendency for the lateral supports to act as stiffeners and may lead to more accurate and reliable results.

There is no doubt that the evidence is sufficient to establish that the defendant is guilty of the crime charged. The evidence is overwhelming and the jury should find the defendant guilty.

assignment.

It is the responsibility of the Government to ensure that the public is not misled by the results of the investigation. It is the responsibility of the Government to ensure that the public is not misled by the results of the investigation.

CONCLUSIONS

1. The apparatus as designed and assembled is capable of applying compressive and shearing forces to the specimens.

2. Although in only one complete series of runs it was found that shear reduced the stability of plating in compression, it is felt that this result may be consistently reproduced if the apparatus is more carefully assembled and aligned.

3. More consistent results are obtained if several runs are made before data is recorded, provided that the specimen is not subjected to the critical shearing force.

4. Bending occurring during compression deflects the plate so that it is no longer subjected to loading only in its own plane, thereby introducing a third and indeterminate type of loading.

5. Buckling may occur shortly before the SR-4 gauges indicate its effect, therefore more gauges on the specimen may be necessary to detect the formation of the initial buckling wave.

Discussion

1. The apparatus is simple and assembled in the
order of application and mounting shown in the

illustration.

2. Although it is a simple matter to turn it
on and off, the apparatus is designed to operate in

operation, it is felt that this device may be used
easily to determine if the specimen is being properly ex-

posed and aligned.

3. More consistent results are obtained if several
turns are made before the specimen is exposed, provided that the

specimen is not subjected to the initial starting force.
4. During operation of the apparatus, the specimen is

placed so that it is in contact with the specimen only
in the one plane. The specimen is held in place

by means of the specimen.

5. During the operation, the specimen is held in place
by means of the specimen, and the specimen is held in place

by means of the specimen, and the specimen is held in place
by means of the specimen.

RECOMMENDATIONS

1. An analysis of the shear distribution linkage system by means of SR-4 gauges should be made to determine the effectiveness of the system and to determine possible improvements.

2. Components of the shear loading device in contact with the plate should be made of a material of low modulus of elasticity to minimize the stiffening effect of the lateral supports.

3. Aligning strips should be extended to reduce the possibility of bending the specimen under a compressive load.

4. The turnbuckle device should be adjusted so that it is free from bending effects and will not cause rotation of the lever plate to which it is attached. Careful adjustment of the shear cable may assist in reducing bending of the turnbuckle. A more permanent location for the strain gauges in the shear system may be desirable inasmuch as it has been frequently found necessary to disconnect the leads from the gauges when rotating the turnbuckle.

Section 1.1

1. The purpose of this section is to provide a brief overview of the system of laws of the State of New York, and to discuss the various ways in which the system is organized and administered.

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APPENDIX

APPENDIX A

DETAILS OF PROCEDURE

Description of Apparatus

Specimen

The specimens were Aluminum plate AL-52- $\frac{1}{2}$ H conforming with Navy Specification 47-A-11. The characteristics of this material are; modulus of elasticity 10,300,000 psi, tensile strength 34,000 psi, yield strength 26,000 psi, shear strength 20,000 psi, endurance limit 18,000 psi, and elongation in 2 inches 12 per cent. The plates were 22.5 inches long and 8 inches wide, the clear dimensions between end compression pieces and between lateral support members thus becoming 21 inches by 6 inches. The latter dimensions were used in all computations for critical buckling loads for a length-width ratio of 3.5 to 1.

The ends of the plate were drilled with $\frac{1}{4}$ inch diameter holes to line-up with those drilled in the end compression attachments. They were spaced $\frac{3}{8}$ inches from the end of the plate and at 1 inch intervals except at the sides where the holes were drilled at $\frac{5}{8}$ inches from the sides so as to be in line with the row of bolts along the lateral support members.

The four holes on either side of the plate which accommodate the four shear distribution pins were $\frac{1}{8}$ inch in diameter and spaced $2 \frac{5}{8}$ inches from either end with $5\frac{1}{4}$ inch spacing between the holes, and $\frac{1}{8}$ inch from the edge of the plate. The holes for the screws holding the lateral supports

APPENDIX A

TESTING OF THE

Development of the

Program

The results of the testing of the program are presented in this appendix. The program was tested on a variety of input data, and the results are shown in the following tables. The first table shows the results of the testing of the program on a set of input data which was chosen to represent a typical set of data. The second table shows the results of the testing of the program on a set of input data which was chosen to represent a set of data which is atypical. The third table shows the results of the testing of the program on a set of input data which was chosen to represent a set of data which is atypical. The fourth table shows the results of the testing of the program on a set of input data which was chosen to represent a set of data which is atypical. The fifth table shows the results of the testing of the program on a set of input data which was chosen to represent a set of data which is atypical.

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in place were approximately $11/64$ inches in diameter, spaced at about 1 inch intervals between the $\frac{1}{8}$ inch holes along the edge, and $5/8$ inches from the edge of the plate.

Lateral Supports

The lateral supports were four in number two on either side, on top and bottom of the plate. They were $3/16$ inch by 1 inch steel strips, 20 $3/4$ inches long. When bolted to the plate specimen there was a gap between them and the end compression attachments of approximately $1/8$ inch. Holes of $11/64$ inch diameter coincided with those drilled in the plate specimen for the 8-32 screws which bolted the lateral supports to the plate. Holes of $5/8$ inch diameter were drilled in the lateral supports, concentric with the four $\frac{1}{8}$ inch holes on each side of the plate. Thus the shear distribution pins did not transmit their force into the lateral supports, but instead, directly into the plate.

Shear Distribution Pins and Linkage Bars.

The four $\frac{1}{8}$ inch diameter pins are shown in sketch in Appendix B as I, II, III, and IV. Pin I is acted upon by a force $F/2$ which is applied at 1 $1/4$ inches on either side of the plate specimen. This force $F/2$ is transmitted from the lever plate through a steel bar $5/16$ inch by 1 inch in cross section. Bar A of cross section $3/16$ inch

In place with approximately 11500 pounds in weight,
spaced at about 1 foot intervals, and 2 inch
apart along the edge, and 200 pounds from the edge of
the plate.

General Remarks

The lateral supports were placed in position and
aligned with the top and bottom of the plate. They were
1/2 inch or 1 inch apart with 1/2 inch between them.
When placed in the plate, the lateral supports were
from the top and bottom of the plate. They were
1/2 inch apart, with 1/2 inch between them. They were
placed in the plate, and the lateral supports were
which placed the lateral supports in the plate. They
of 1/2 inch diameter were placed in the lateral supports.
approximately with the top and bottom of the plate.
plate. The lateral supports were placed in the plate.
plate force into the lateral supports, and placed in
plate into the plate.

Special Observations on the Lateral Supports

The top 1 inch of the plate was placed in
approximately 1 inch, 1/2 inch, and 1/2 inch from the
a force of 1/2 inch was applied to the top of the
edge of the plate. The lateral supports were placed
from the top of the plate. The lateral supports were
from the top of the plate. The lateral supports were
from the top of the plate. The lateral supports were

by 1 inch acts at a point 1 inch on either side of the plate. The position of Bar A was calculated to transmit a force $F/4$ into the plate at the center of pin I. Bars B and C were similarly located, so that one fourth of the applied shear load is transmitted into the plate at the center of pins II, III, and IV. Bars A, B, and C each have $\frac{1}{2}$ inch diameter holes drilled on $5\frac{1}{4}$ inch centers. Bar A pulls on pin II at 1 inch from the pin center. Bar B of cross section $\frac{1}{4}$ inch by $\frac{7}{8}$ inch pulls on pin II at $\frac{3}{4}$ inch from the pin center, and also on pin III at the same location. Bar C of cross section $\frac{1}{4}$ inch by 1 inch pulls on pin IV at $\frac{1}{2}$ inch from the pin center. The bars A, B, and C are held at their correct position by insertion of spacers concentric with the pins. The sample calculations for this distribution system are given in Appendix B.

Aligning Strips

Short sections of $1/8$ inch by 1 inch steel strips approximately 3 inches long were bolted at each of the four corners of the plate, one piece on both top and bottom. Two holes were drilled to coincide with the $11/64$ inch holes drilled in the lateral supports, and a third hole was concentric with the $\frac{1}{4}$ inch hole in the compression attachment, which was $5/8$ inch from its edge. This latter hole was enlarged considerably to permit relative

... and also in ...

movement of the lateral supports, and the compression attachments. The purpose of these pieces of metal was to prevent unintentional bending of the plate specimen between the end compression attachments and lateral supports, and yet permit the compressive force to be exerted directly on the plate without being introduced into the lateral support members.

Compression Attachments

The two identical compression attachments consisted of a section of $1\frac{1}{4}$ inch standard steel pipe 8 inches long, to which was welded a piece of $\frac{1}{2}$ inch steel plate 8 inches long by $3\frac{1}{4}$ inches wide, so that the steel plate extended radially outward from the center of the steel pipe. The outer 8 inch by $\frac{1}{2}$ inch edge of this plate had a slot milled $\frac{3}{4}$ inch deep by $\frac{1}{8}$ inch wide centrally located along this edge. The $\frac{1}{4}$ inch holes drilled at $\frac{3}{8}$ inches from the edge and equally spaced at 1 inch intervals corresponded to those drilled in the end of the plate specimen. A $\frac{3}{8}$ inch hole was drilled at 1 $\frac{3}{4}$ inches from the outer edge and 2 inches from one side to provide the connection for the linkage bars to the lever plate.

End Frames

The two end frames were identical in construction. The material consisted of $\frac{1}{4}$ inch mild steel plate, joined to sections of 1 inch extra strong steel pipe and $1\frac{1}{4}$ inch

on the plate without being subjected into the lateral

standard steel pipe. The $1\frac{1}{2}$ inch pipe with inner diameter 1.380 inches permits the 1 inch pipe with outer diameter 1.315 inches to fit loosely within it and forms the pivoting axes of the compressing device. The distance center to center from the lower pipe section to the upper pipe section was 9 inches. The distance from center of the lower pipe section to the vertical mounted reinforcing plate section was 3 feet. It was beneath this reinforced section at which the hydraulic jack force was applied at one end, and beneath which a line of contact with the balance scale was established on the other end. These dimensions gave a 4 to 1 ratio between applied force and that actually exerted on the plate specimen.

Balance Scale and Hydraulic Jack

The balance scale capacity was 1000 pounds. It was this value which established the maximum design conditions in this investigation. The hydraulic jack, which was purchased commercially, had a capacity of 3 tons.

Lever Plates

The two identical lever plates were constructed from $\frac{1}{4}$ inch steel plate, cut to provide clearance for operation of the apparatus. Three $\frac{1}{4}$ inch holes were positioned so that their centers formed a right triangle with the longer leg $17\frac{1}{2}$ inches and the shorter leg 5 inches, main-

taining the 3.5 to 1 ratio of the plate specimen.

Turnbuckle and Strain Gauge Device

This device was designed by the authors and was made by the M.I.T. Civil Engineering Structural Laboratory personnel. Two flat areas were milled on diametrically opposite sides of a piece of 1 inch diameter bar stock. Cross sectional area of bar between milled flats was 0.6075 sq. inches. Width of milled section was 0.75 inches, and the length approximately $2\frac{1}{4}$ inches. The length of the threaded travel was 4 inches.

Wire Rope

The shearing force was applied through approximately 14 feet of 6 x 19 $\frac{1}{8}$ inch wire rope which has the following characteristics; metallic area 0.098 sq.in., modulus of elasticity 12,000,000 lbs./sq. in., and breaking strength 9.35 tons. This wire rope was connected to the lever plate directly on one end by a standard $\frac{3}{4}$ inch shackle, and on the other end to the turnbuckle by the same size shackle with modifications to suit the design.

I-Beam and Sheaves

The I-beam was a standard 6 x 4 x 12# beam which had a section modulus of 1.44 inches cubed, for the position in which mounted. At each end 10 inches of the web was removed to permit insertion of sheaves. These were standard 12 inch sheaves, bronze bushed, with 1 inch diameter shafts.

...and the ...

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This device was built by the author and was made by the M.I.T. Civil Engineering Laboratory personnel. The first tests were made on specimens of concrete at a depth of 1 inch diameter and were successful. The second series of tests were made on specimens of concrete at a depth of 2 inches and were also successful. The third series of tests were made on specimens of concrete at a depth of 3 inches and were also successful. The fourth series of tests were made on specimens of concrete at a depth of 4 inches and were also successful. The fifth series of tests were made on specimens of concrete at a depth of 5 inches and were also successful. The sixth series of tests were made on specimens of concrete at a depth of 6 inches and were also successful. The seventh series of tests were made on specimens of concrete at a depth of 7 inches and were also successful. The eighth series of tests were made on specimens of concrete at a depth of 8 inches and were also successful. The ninth series of tests were made on specimens of concrete at a depth of 9 inches and were also successful. The tenth series of tests were made on specimens of concrete at a depth of 10 inches and were also successful.

The shafts were supported by the two flanges of the I-beam, through which 1 inch diameter holes were drilled. The holes for these shafts were 4 feet 9 inches from the center of the beam. The I-beam was supported by 2 x 4 pine members, bolted at each end so that the center of the sheave shafts were approximately 5 feet above the floor level.

Shearing Force Jack

The vertical jack screw at the center of the beam held the center of the wire rope at approximately $10\frac{1}{4}$ inches above the center of the web of the beam. An additional travel of $4\frac{1}{2}$ inches was available on the threaded portion of the screw to raise the wire height to approximately 15 inches above the center of the web. The vertical movement of this screw was designed to transmit 10,000 lbs into the wire rope, however this force was subject to variation, dependent on the initial force in the cable when the turnbuckle was tightened. In the tests performed, forces as great as 4000 lbs. were measured.

Strain Gauges and Strain Indicator

The SR-4 strain gauges were Bonded Resistance Wire Gauges manufactured by the Baldwin Southwark Division, Baldwin Locomotive Works. The specific gauge used was an A-11, 119.2 ohm, with gauge factor 2.04. The strain

readings were obtained by the use of an SR-4 Strain Gauge Indicator, also manufactured by Baldwin. The strain gauges were mounted on both sides of the plate specimen, and at the center of the plate, with their axis parallel to the longer dimension of the plate.

Figure XVII

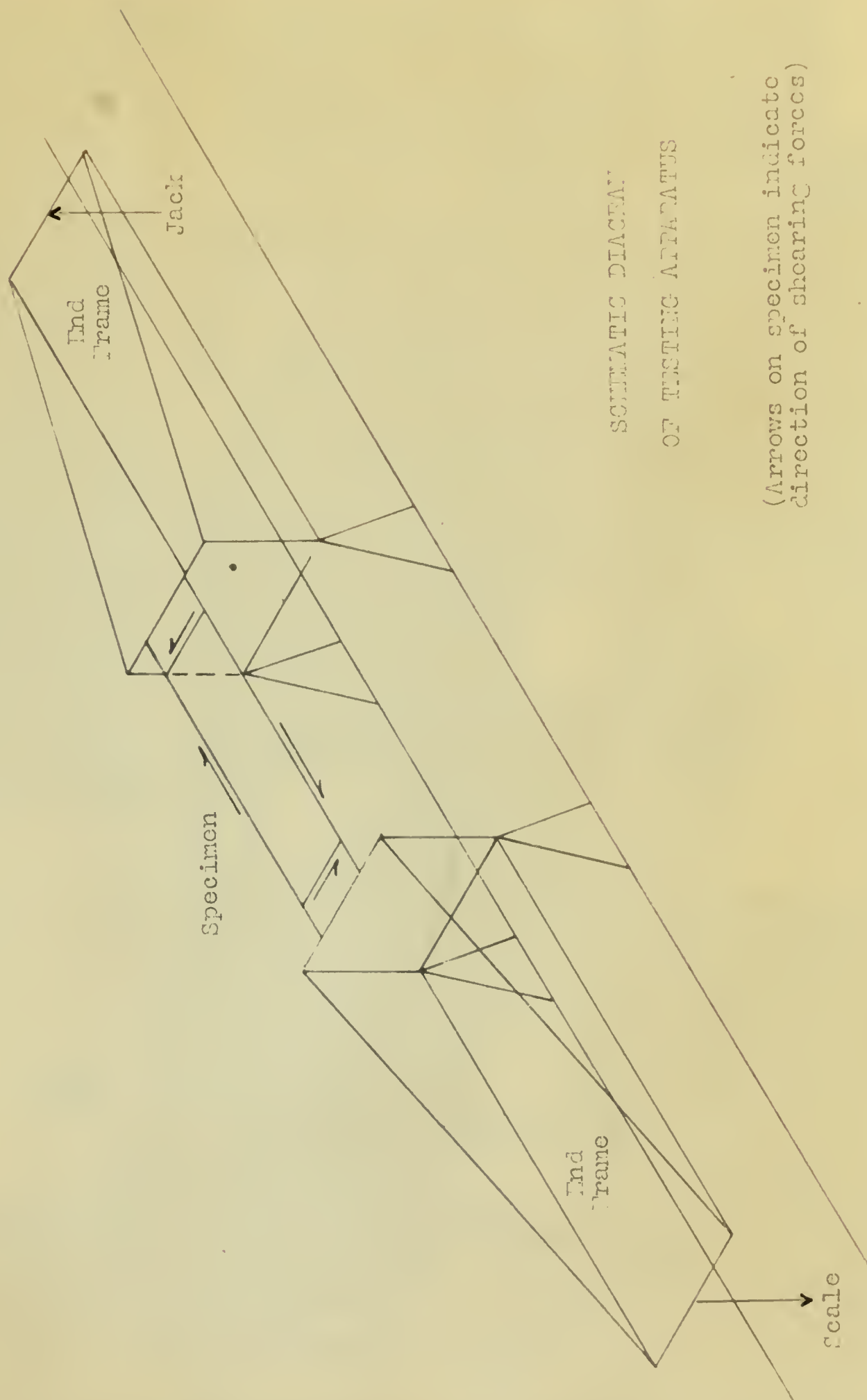


Figure XVIII

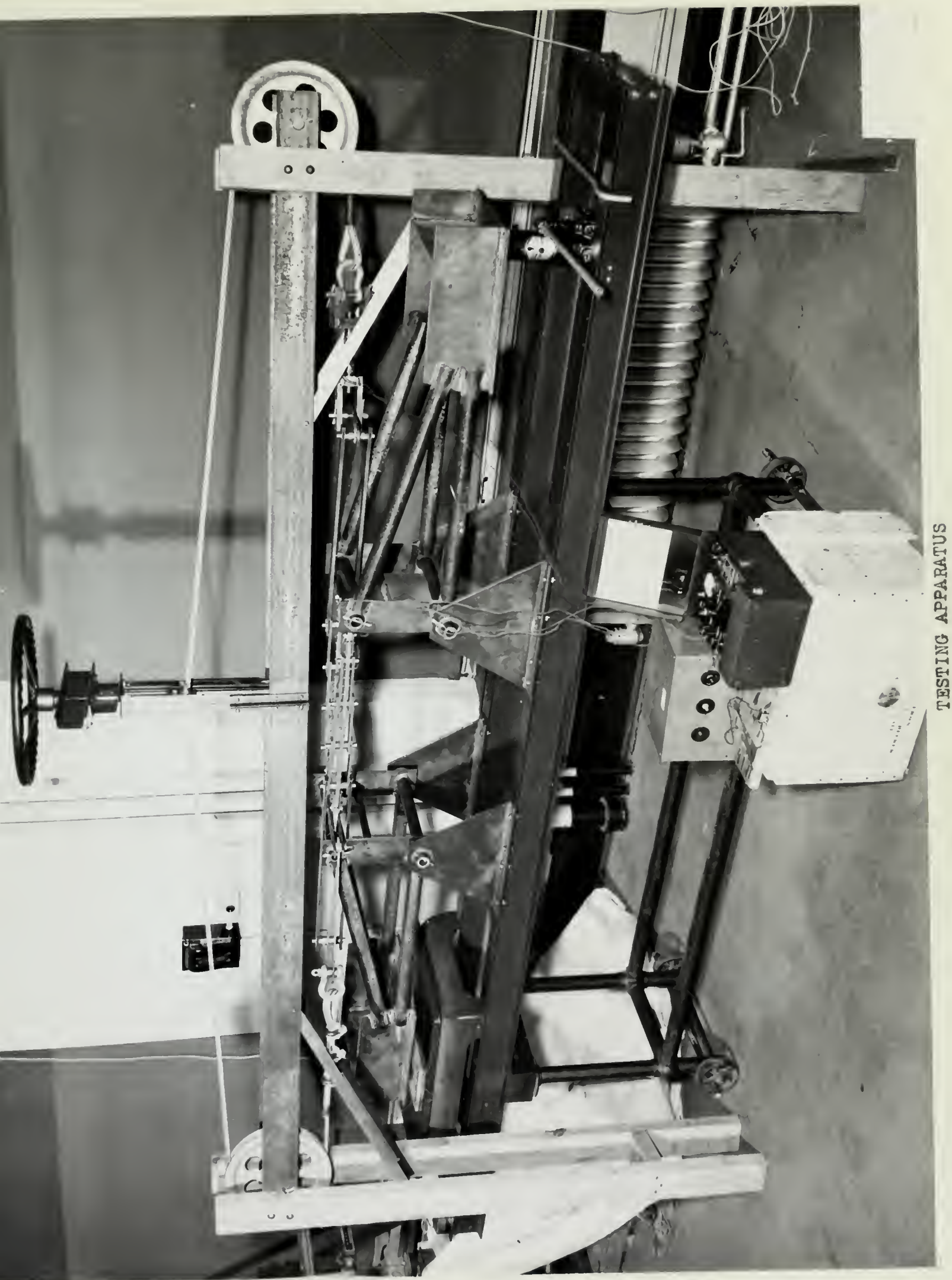


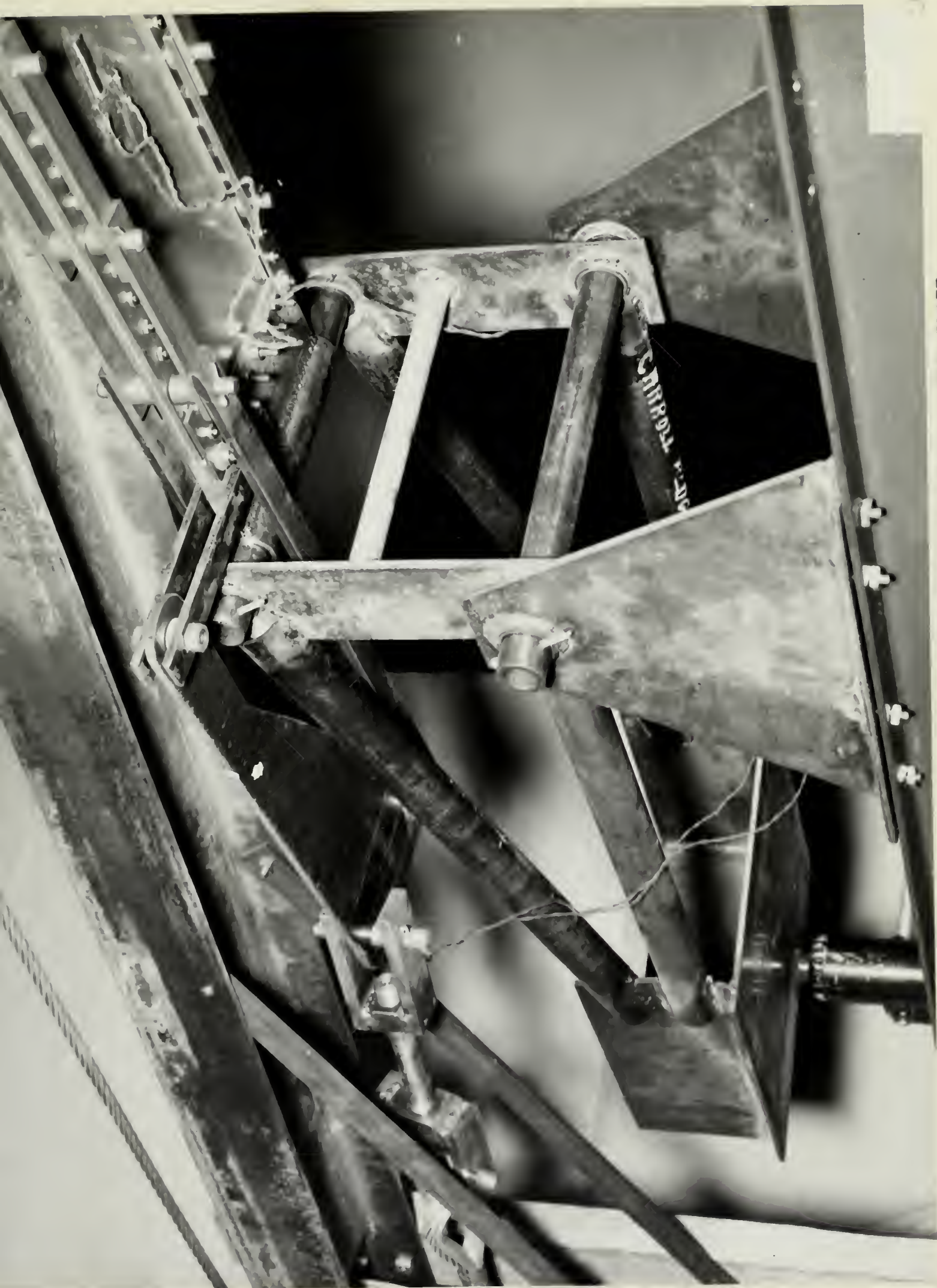
Figure XIX



PLATE SPECIMEN AND SHEAR TEST APPARATUS

THE UNIVERSITY OF CHICAGO

Figure XX



TURNBUCKLE AND STRAIN GAUGE DEVICE CONNECTED TO LEVER PLATE

CONFIDENTIAL AND SECRET HAVE BEEN COMBINED TO FORM ONE

ANALYSIS CALCULATIONCalculation for Theoretical Critical Value of Stress

Formulas for Critical stress:

$$\text{Compressive stress: } \sigma_{CR} = K \frac{\pi^2 E}{12(1-\nu^2)} \times \frac{t^3}{L^2}$$

$$\text{Shear stress: } \tau_{CR} = K_s \frac{\pi^2 E}{12(1-\nu^2)} \times \frac{t^3}{L^2}$$

For plate freely supported on all four sides and with length-

to-width ratio of 3.5 -

$$K = 4.00$$

$$K_s = 5.40$$

Formulas and constant from Timoshenko (2).

In the above formulas -

E is the modulus of elasticity of the material and equals 10,300,000 pounds per square inch.

 ν is Poisson's ratio and equals 0.23.

t is plate thickness.

b is plate width, assumed to be 6 inches.

Specimen	t, inches	σ_{CR} , kips/in. \times	τ_{CR} , kips/in. \times	Max. Comp. Force, kips	Max. Shear Force, kips
No.1	0.039	1.609	2.170	0.376	1.845
No.2	0.038	1.150	1.552	0.328	1.113
No.3	0.038	1.150	1.552	0.328	1.113
No.4	0.0395	1.650	2.125	0.391	1.820
No.5	0.064	4.230	5.840	1.662	8.150
No.6	0.065	4.460	6.030	1.742	8.545
No.7	0.030	0.952	1.282	0.171	0.840

The maximum compressive force is obtained by multiplying the critical compressive stress by the cross-sectional area of the specimen.

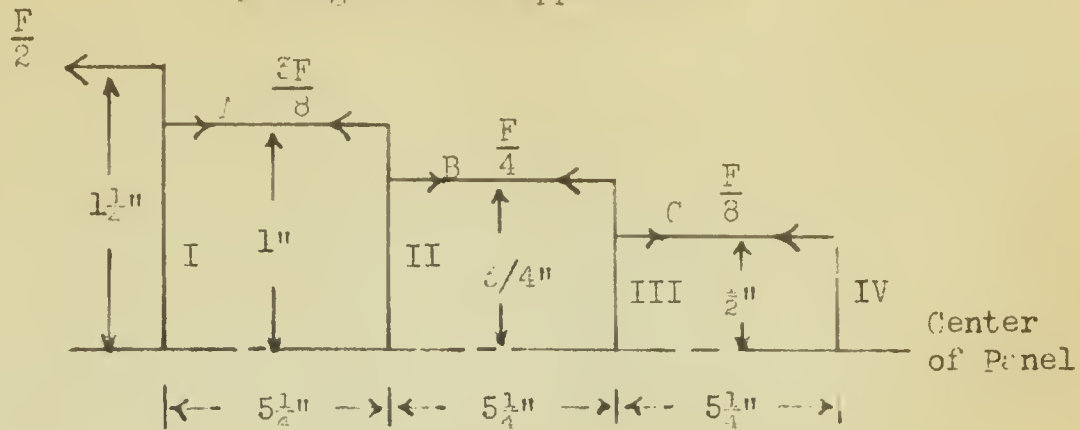
The maximum shear force is obtained by multiplying the critical shear stress by the product of the thickness, t, and the length. It is further corrected by resolving it to the component along the diagonal of the specimen, in which direction the measurements of shear force were obtained.

APPENDIX B

SAMPLE CALCULATION

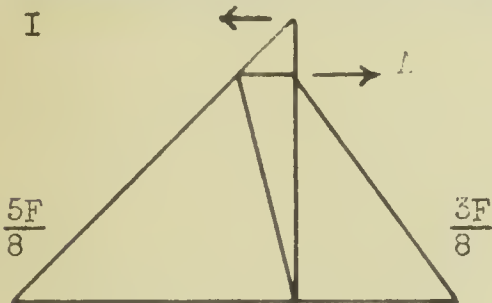
Apparatus for Uniform Distribution of Shearing Force on Side of Panel

Arrangement of Apparatus



Determination of Deflections of Pins

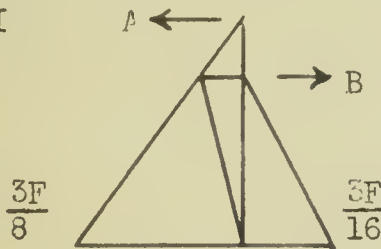
I



$$\Delta_{IA} = \frac{1}{EI} \left(\frac{5F}{8} \times \frac{1}{2} \times \frac{2}{3} + \frac{F}{8} \times \frac{1}{2} \times \frac{1}{3} - \frac{3F}{8} \times \frac{1}{2} \times \frac{2}{3} \right)$$

$$= 0.104 \frac{F}{EI}$$

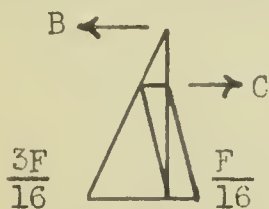
II



$$\Delta_{IIA} = 0.072 \frac{F}{EI}$$

$$\Delta_{IIB} = 0.044 \frac{F}{EI}$$

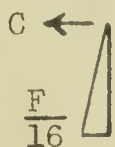
III



$$\Delta_{IIIB} = 0.026 \frac{F}{EI}$$

$$\Delta_{IIIC} = 0.013 \frac{F}{EI}$$

IV



$$\Delta_{IIIC} = 0.0052 \frac{F}{EI}$$

APPENDIX B

SAMPLE CALCULATIONS

Determination of Elongation of Bars

$$A: \Delta = \frac{PL}{AE} = \frac{\frac{3F}{8} \times 5\frac{1}{4}}{AE} = 1.97 \frac{F}{AE}$$

$$B: \Delta = \frac{PL}{AE} = \frac{\frac{F}{4} \times 5\frac{1}{4}}{AE} = 1.31 \frac{F}{AE}$$

$$C: \Delta = \frac{PL}{AE} = \frac{\frac{F}{8} \times 5\frac{1}{4}}{AE} = 0.66 \frac{F}{AE}$$

Pin Diameters Assumed to be $\frac{1}{2}$ "

$$I = \frac{\pi d^4}{64} = 0.00307 \text{ in}^4$$

Required Elongations of Bars

$$\Delta_{IA} - \Delta_{HA} = 10.5 \frac{F}{E} = \Delta_A$$

$$\Delta_{IB} - \Delta_{HB} = 5.8 \frac{F}{E} = \Delta_B$$

$$\Delta_{IC} - \Delta_{HC} = 0.6 \frac{F}{E} = \Delta_C$$

Required Cross-Sectional Areas of Bars

$$A_A = \frac{1.97}{10.5} = 0.1875 \text{ in}^2$$

$$A_B = \frac{1.31}{5.8} = 0.226 \text{ in}^2$$

$$A_C = \frac{0.66}{0.6} = 0.11 \text{ in}^2$$

APPENDIX C

ORIGINAL DATA

Specimen: Plate No. 1

Plate thickness: 0.039 inches

Conditions: Lateral supports of $\frac{1}{4}$ inch by 1 inch cross section. Bolt holes in lateral supports $\frac{1}{4}$ inch diameter spaced at 1 inch intervals. Size 12-24 bolts used in the $\frac{1}{4}$ inch holes. Used $\frac{1}{4}$ inch bolts in end compression attachment holes. Shear force attachments disconnected from the plate specimen. All bolts finger tight.

RUN No. 1 Date: 24 March 1949

RUN No. 2 Date: 24 March 1949

Type: Pure Compression

Type: Pure Compression

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

72	- 25	- 19
----	------	------

204	- 72	- 54
-----	------	------

288	- 110	- 89
-----	-------	------

352	- 142	- 101
-----	-------	-------

480	- 198	- 102
-----	-------	-------

580	- 246	- 103
-----	-------	-------

676	- 311	- 83
-----	-------	------

780	- 391	- 43
-----	-------	------

896	- 423	- 7
-----	-------	-----

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

42	- 19	- 32
----	------	------

78	- 49	- 47
----	------	------

120	- 51	- 61
-----	------	------

156	- 93	- 86
-----	------	------

280	- 111	- 85
-----	-------	------

323	- 129	- 89
-----	-------	------

388	- 131	- 102
-----	-------	-------

440	- 150	- 115
-----	-------	-------

476	- 173	- 125
-----	-------	-------

524	- 200	- 124
-----	-------	-------

556	- 226	- 123
-----	-------	-------

596	- 258	- 106
-----	-------	-------

640	- 289	- 96
-----	-------	------

680	- 318	- 64
-----	-------	------

712	- 324	- 53
-----	-------	------

760	- 348	- 37
-----	-------	------

800	- 376	- 23
-----	-------	------

832	- 392	- 5
-----	-------	-----

TESTING DATA

Goodman: Plate No. 1 Plate Thickness: 0.005 inches

Condition: Physical properties of 1/2 inch by 1 inch stress relieved, mild steel in lateral supports 1/2 inch diameter spaced at 1 inch intervals. With 1/2 inch bolts in the 1/2 inch holes. Used 1 inch bolts in end supports as- shown below. Sheet for stress analysis of Goodman plate. Sheet for stress analysis of Goodman plate. All bolts tight.

RUN No. 1 Date: 14 March 1949 RUN No. 2 Date: 14 March 1949

Type: Pure Tension Type: Pure Tension

Axial Compressive Load (lbs)	Plate	Strain Gauge (Average of 100 of 1000 of Load (lbs))	Axial Compressive Load (lbs)	Plate	Strain Gauge (Average of 100 of 1000 of Load (lbs))
72	-	10	72	-	10
104	-	15	104	-	15
136	-	20	136	-	20
168	-	25	168	-	25
200	-	30	200	-	30
232	-	35	232	-	35
264	-	40	264	-	40
296	-	45	296	-	45
328	-	50	328	-	50
360	-	55	360	-	55
392	-	60	392	-	60
424	-	65	424	-	65
456	-	70	456	-	70
488	-	75	488	-	75
520	-	80	520	-	80
552	-	85	552	-	85
584	-	90	584	-	90
616	-	95	616	-	95
648	-	100	648	-	100
680	-	105	680	-	105
712	-	110	712	-	110
744	-	115	744	-	115
776	-	120	776	-	120
808	-	125	808	-	125
840	-	130	840	-	130
872	-	135	872	-	135
904	-	140	904	-	140
936	-	145	936	-	145
968	-	150	968	-	150

Specimen: Plate No. 1

Plate thickness: 0.039 inches

Conditions: The same as Run No. 1.

RUN No. 3

Date: 31 March 1949

Type: Pure Compression

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	<u>Top of Plate</u>	<u>Bottom of Plate</u>
94	- 33	- 28
178	- 59	- 53
256	- 93	- 74
336	- 123	- 97
396	- 104	- 74
480	- 163	- 104
572	- 233	- 100
652	- 284	- 82
712	- 301	- 23
784	- 341	+ 3

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Specimen: Plate No. 1

Plate thickness: 0.039 inches

Conditions: Lateral supports the same as Run No. 1 with the exception that $\frac{1}{4}$ inch bolts were used in the $\frac{1}{4}$ inch bolt holes of the lateral supports. All other conditions the same as Run No. 1.

RUN No. 4 Date: 5 April 1949

RUN No. 5 Date: 5 April 1949

Type: Pure Compression

Type: Pure Compression

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

108	- 30	- 30
-----	------	------

208	- 70	- 66
-----	------	------

300	- 107	- 103
-----	-------	-------

364	- 126	- 121
-----	-------	-------

440	- 152	- 153
-----	-------	-------

520	- 169	- 182
-----	-------	-------

596	- 179	- 211
-----	-------	-------

680	- 147	- 269
-----	-------	-------

736	- 113	- 321
-----	-------	-------

828	- 30	- 374
-----	------	-------

904	+ 17	- 424
-----	------	-------

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

112	- 22	- 22
-----	------	------

216	- 58	- 59
-----	------	------

284	- 83	- 87
-----	------	------

356	- 108	- 110
-----	-------	-------

444	- 138	- 143
-----	-------	-------

524	- 162	- 181
-----	-------	-------

620	- 162	- 231
-----	-------	-------

656	- 138	- 272
-----	-------	-------

756	- 81	- 352
-----	------	-------

848	- 62	- 393
-----	------	-------

928	- 53	- 409
-----	------	-------

Reel No. 1 Plate No. 1

Condition: lateral supports the same as Run No. 1 with the same
 film runs 4 inch bolts were used in the 1 inch hole
 holes of the lateral supports. All other conditions
 the same as Run No. 1.

Run No. 4 Date: 5 April 1940 Run No. 5 Date: 5 April 1940

Type: Type Compression Type: Type Compression

Actual
 Compressive (lb-in)
 Top of
 Plate

108	- 30	- 30	118	- 38	- 38
109	- 40	- 40	119	- 48	- 48
110	- 107	- 107	120	- 63	- 63
111	- 118	- 118	121	- 108	- 110
112	- 128	- 128	122	- 138	- 140
113	- 138	- 138	123	- 148	- 148
114	- 148	- 148	124	- 158	- 161
115	- 178	- 178	125	- 188	- 191
116	- 188	- 188	126	- 198	- 198
117	- 198	- 198	127	- 208	- 208
118	- 208	- 208	128	- 218	- 218
119	- 218	- 218	129	- 228	- 228
120	- 228	- 228	130	- 238	- 238
121	- 238	- 238	131	- 248	- 248
122	- 248	- 248	132	- 258	- 258
123	- 258	- 258	133	- 268	- 268
124	- 268	- 268	134	- 278	- 278
125	- 278	- 278	135	- 288	- 288
126	- 288	- 288	136	- 298	- 298
127	- 298	- 298	137	- 308	- 308
128	- 308	- 308	138	- 318	- 318
129	- 318	- 318	139	- 328	- 328
130	- 328	- 328	140	- 338	- 338
131	- 338	- 338	141	- 348	- 348
132	- 348	- 348	142	- 358	- 358
133	- 358	- 358	143	- 368	- 368
134	- 368	- 368	144	- 378	- 378
135	- 378	- 378	145	- 388	- 388
136	- 388	- 388	146	- 398	- 398
137	- 398	- 398	147	- 408	- 408
138	- 408	- 408	148	- 418	- 418
139	- 418	- 418	149	- 428	- 428
140	- 428	- 428	150	- 438	- 438
141	- 438	- 438	151	- 448	- 448
142	- 448	- 448	152	- 458	- 458
143	- 458	- 458	153	- 468	- 468
144	- 468	- 468	154	- 478	- 478
145	- 478	- 478	155	- 488	- 488
146	- 488	- 488	156	- 498	- 498
147	- 498	- 498	157	- 508	- 508
148	- 508	- 508	158	- 518	- 518
149	- 518	- 518	159	- 528	- 528
150	- 528	- 528	160	- 538	- 538
151	- 538	- 538	161	- 548	- 548
152	- 548	- 548	162	- 558	- 558
153	- 558	- 558	163	- 568	- 568
154	- 568	- 568	164	- 578	- 578
155	- 578	- 578	165	- 588	- 588
156	- 588	- 588	166	- 598	- 598
157	- 598	- 598	167	- 608	- 608
158	- 608	- 608	168	- 618	- 618
159	- 618	- 618	169	- 628	- 628
160	- 628	- 628	170	- 638	- 638
161	- 638	- 638	171	- 648	- 648
162	- 648	- 648	172	- 658	- 658
163	- 658	- 658	173	- 668	- 668
164	- 668	- 668	174	- 678	- 678
165	- 678	- 678	175	- 688	- 688
166	- 688	- 688	176	- 698	- 698
167	- 698	- 698	177	- 708	- 708
168	- 708	- 708	178	- 718	- 718
169	- 718	- 718	179	- 728	- 728
170	- 728	- 728	180	- 738	- 738
171	- 738	- 738	181	- 748	- 748
172	- 748	- 748	182	- 758	- 758
173	- 758	- 758	183	- 768	- 768
174	- 768	- 768	184	- 778	- 778
175	- 778	- 778	185	- 788	- 788
176	- 788	- 788	186	- 798	- 798
177	- 798	- 798	187	- 808	- 808
178	- 808	- 808	188	- 818	- 818
179	- 818	- 818	189	- 828	- 828
180	- 828	- 828	190	- 838	- 838
181	- 838	- 838	191	- 848	- 848
182	- 848	- 848	192	- 858	- 858
183	- 858	- 858	193	- 868	- 868
184	- 868	- 868	194	- 878	- 878
185	- 878	- 878	195	- 888	- 888
186	- 888	- 888	196	- 898	- 898
187	- 898	- 898	197	- 908	- 908
188	- 908	- 908	198	- 918	- 918
189	- 918	- 918	199	- 928	- 928
190	- 928	- 928	200	- 938	- 938
191	- 938	- 938	201	- 948	- 948
192	- 948	- 948	202	- 958	- 958
193	- 958	- 958	203	- 968	- 968
194	- 968	- 968	204	- 978	- 978
195	- 978	- 978	205	- 988	- 988
196	- 988	- 988	206	- 998	- 998
197	- 998	- 998	207	- 1008	- 1008
198	- 1008	- 1008	208	- 1018	- 1018
199	- 1018	- 1018	209	- 1028	- 1028
200	- 1028	- 1028	210	- 1038	- 1038
201	- 1038	- 1038	211	- 1048	- 1048
202	- 1048	- 1048	212	- 1058	- 1058
203	- 1058	- 1058	213	- 1068	- 1068
204	- 1068	- 1068	214	- 1078	- 1078
205	- 1078	- 1078	215	- 1088	- 1088
206	- 1088	- 1088	216	- 1098	- 1098
207	- 1098	- 1098	217	- 1108	- 1108
208	- 1108	- 1108	218	- 1118	- 1118
209	- 1118	- 1118	219	- 1128	- 1128
210	- 1128	- 1128	220	- 1138	- 1138
211	- 1138	- 1138	221	- 1148	- 1148
212	- 1148	- 1148	222	- 1158	- 1158
213	- 1158	- 1158	223	- 1168	- 1168
214	- 1168	- 1168	224	- 1178	- 1178
215	- 1178	- 1178	225	- 1188	- 1188
216	- 1188	- 1188	226	- 1198	- 1198
217	- 1198	- 1198	227	- 1208	- 1208
218	- 1208	- 1208	228	- 1218	- 1218
219	- 1218	- 1218	229	- 1228	- 1228
220	- 1228	- 1228	230	- 1238	- 1238
221	- 1238	- 1238	231	- 1248	- 1248
222	- 1248	- 1248	232	- 1258	- 1258
223	- 1258	- 1258	233	- 1268	- 1268
224	- 1268	- 1268	234	- 1278	- 1278
225	- 1278	- 1278	235	- 1288	- 1288
226	- 1288	- 1288	236	- 1298	- 1298
227	- 1298	- 1298	237	- 1308	- 1308
228	- 1308	- 1308	238	- 1318	- 1318
229	- 1318	- 1318	239	- 1328	- 1328
230	- 1328	- 1328	240	- 1338	- 1338
231	- 1338	- 1338	241	- 1348	- 1348
232	- 1348	- 1348	242	- 1358	- 1358
233	- 1358	- 1358	243	- 1368	- 1368
234	- 1368	- 1368	244	- 1378	- 1378
235	- 1378	- 1378	245	- 1388	- 1388
236	- 1388	- 1388	246	- 1398	- 1398
237	- 1398	- 1398	247	- 1408	- 1408
238	- 1408	- 1408	248	- 1418	- 1418
239	- 1418	- 1418	249	- 1428	- 1428
240	- 1428	- 1428	250	- 1438	- 1438
241	- 1438	- 1438	251	- 1448	- 1448
242	- 1448	- 1448	252	- 1458	- 1458
243	- 1458	- 1458	253	- 1468	- 1468
244	- 1468	- 1468	254	- 1478	- 1478
245	- 1478	- 1478	255	- 1488	- 1488
246	- 1488	- 1488	256	- 1498	- 1498
247	- 1498	- 1498	257	- 1508	- 1508
248	- 1508	- 1508	258	- 1518	- 1518
249	- 1518	- 1518	259	- 1528	- 1528
250	- 1528	- 1528	260	- 1538	- 1538
251	- 1538	- 1538	261	- 1548	- 1548
252	- 1548	- 1548	262	- 1558	- 1558
253	- 1558	- 1558	263	- 1568	- 1568
254	- 1568	- 1568	264	- 1578	- 1578
255	- 1578	- 1578	265	- 1588	- 1588
256	- 1588	- 1588	266	- 1598	- 1598
257	- 1598	- 1598	267	- 1608	- 1608
258	- 1608	- 1608	268	- 1618	- 1618
259	- 1618	- 1618	269	- 1628	- 1628
260	- 1628	- 1628	270	- 1638	- 1638
261	- 1638	- 1638	271	- 1648	- 1648
262	- 1648	- 1648	272	- 1658	- 1658
263	- 1658	- 1658	273	- 1668	- 1668
264	- 1668	- 1668	274	- 1678	- 1678
265	- 1678	- 1678	275	- 1688	- 1688
266	- 1688	- 1688	276	- 1698	- 1698
267	- 1698	- 1698	277	- 1708	- 1708
268	- 1708	- 1708	278	- 1718	- 1718
269	- 1718	- 1718	279	- 1728	- 1728
270	- 1728	- 1728	280	- 1738	- 1738
271	- 1738	- 1738	281	- 1748	- 1748
272	- 1748	- 1748	282	- 1758	- 1758
273	- 1758	- 1758	283	- 1768	- 1768
274	- 1768	- 1768	284	- 1778	- 1778
275	- 1778	- 1778	285	- 1788	- 1788
276	- 1788	- 1788	286	- 1798	- 1798
277	- 1798	- 1798	287	- 1808	- 1808
278	- 1808	- 1808	288	- 1818	- 1818
279	- 1818	- 1818	289	- 1828	- 1828
280	- 1828	- 1828	290	- 1838	- 1838
281	- 1838	- 1838	291	- 1848	- 1848
282	- 1848	- 1848	292	- 1858	- 1858
283	- 1858	- 1858	293	- 1868	- 1868
284	- 1868	- 1868	294	- 1878	- 1878
285	- 1878	- 1878	295	- 1888	- 1888
286	- 1888	- 1888	296	- 1898	- 1898
287	- 1898	- 1898	297	- 1908	- 1908
288	- 1908	- 1908	298	- 1918	- 1918
289	- 1918	- 1918	299	- 1928	- 1928
290	- 1928	- 1928	300	- 1938	- 1938
291	- 1938	- 1938	301	- 1948	- 1948
292	- 1948	- 1948	302	- 1958	- 1958
293	- 1958	- 1958	303	- 1968	- 1968
294	- 1968	- 1968	304	- 1978	- 1978
295	- 1978	- 1978	305	- 1988	- 1988
296	- 1988	- 1988	306	- 1998	- 1998
297	- 1998	- 1998	307	- 2008	- 2008
298	- 2008	- 2008	308	- 2018	- 2018
299	- 2018	- 2018	309	- 2028	- 2028
300	- 2028	- 2028	310	- 2038	- 2038
301	- 2038	- 2038	311</		

Specimen: Plate No. 2

Plate thickness: 0.033 inches

Conditions: Lateral supports of cross section 3/16 inch by 1 inch, bolt holes 11/64 inch diameter, lateral supports held to plate specimen by 8-32 size screws, finger tight. Shear force attachments connected to plate specimen.

RUN No. 6 Date: 20 April 1949

RUN No. 7 Date: 21 April 1949

Type: Pure Compression

Type: Pure Shear

Axial Compressive Load (lbs)	Strain Gauge (micro-in.)	
	Top of Plate	Bottom of Plate

Shear Force Along Diag. (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

136	- 46	- 43
-----	------	------

173	+ 38	+ 29
-----	------	------

220	- 60	- 70
-----	------	------

420	+ 86	+ 78
-----	------	------

304	- 108	- 90
-----	-------	------

675	+ 134	+ 120
-----	-------	-------

404	- 159	- 110
-----	-------	-------

911	+ 178	+ 159
-----	-------	-------

472	- 202	- 115
-----	-------	-------

1220	+ 211	+ 188
------	-------	-------

552	- 277	- 98
-----	-------	------

1550	+ 252	+ 220
------	-------	-------

572	- 301	- 81
-----	-------	------

1895	+ 281	+ 229
------	-------	-------

2015	+ 297	+ 228
------	-------	-------

2115	+ 301	+ 210
------	-------	-------

2225	+ 329	+ 201
------	-------	-------

2285	+ 334	+ 199
------	-------	-------

Specimen: Plate No. 2

Plate thickness: 0.033 inches

Conditions: The same as Run No. 6.

RUN No. 8 Date: 21 April 1949

RUN No. 9 Date: 21 April 1949

Type: Combined Compression and Shear.
Constant shear force along the
diagonal 286 pounds.

Type: Combined Compression and
Shear. Constant shear force
along the diagonal 635
pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)		Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate		Top of Plate	Bottom of Plate
136	+ 6	- 1	64	+ 39	+ 28
224	- 19	- 22	156	+ 11	+ 7
312	- 51	- 40	220	- 8	- 16
356	- 79	- 54	316	- 28	- 39
436	- 119	- 61	384	- 61	- 61
540	- 187	- 44	468	- 87	- 73
612	- 269	+ 26	500	- 92	- 79
			540	- 110	- 85
			600	- 138	- 100
			636	- 156	- 102
			684	- 184	- 102
			708	- 200	- 100
			740	- 228	- 90

Specimen: Plate No. 2

Plate thickness: 0.035 inches

Conditions: The same as Run No. 6.

RUN No. 10

Date: 21 April 1949

Type: Combined Compression and Shear.
Constant shear force along the
diagonal 1015 pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate
8	+ 56	+ 41
164	+ 25	+ 9
236	+ 5	- 9
332	- 33	- 45
396	- 53	- 58
472	- 64	- 68
532	- 78	- 78
600	- 94	- 89
624	- 103	- 97
664	- 113	- 104
720	- 135	- 117
752	- 143	- 121
768	- 154	- 127
824	- 175	- 139
868	- 193	- 141
900	- 206	- 147
940	- 226	- 140
972	- 254	- 107

Specimen: Plate No. 2

Plate thickness: 0.053 inches

Conditions: Lateral supports of cross section 3/16 inch by 1 inch, bolt holes 11/64 inch diameter, lateral supports and plate specimen joined by 8-32 size screws, finger tight. Shear force attachments connected to the plate specimen.

RUN No. 11 Date: 27 April 1949

RUN No. 12 Date: 27 April 1949

Type: Pure Compression

Type: Pure Compression

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate
122	- 36	- 29
198	- 69	- 41
314	- 118	- 52
370	- 152	- 40
394	- 168	- 30

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate
136	- 38	- 31
208	- 70	- 42
324	- 120	- 50
376	- 127	- 41
424	- 162	- 29

Specimen: Plate No. 3

Plate thickness: 0.033 inches

Conditions: The same as Run No. 11.

RUN No. 13 Date: 27 April 1949

RUN No. 14 Date: 27 April 1949

Type: Pure Shear

Type: Combined Compression and Shear.
Constant shear force along the
diagonal 27 pounds

Shear Force Along Diag. (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate
45	+ 1	0
91	- 18	- 10
228	- 53	- 34
237	- 65	- 56
282	- 79	- 58
310	- 91	- 58
337	- 110	- 58
365	- 135	- 27
410	- 161	- 10

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate
132	- 45	- 28
214	- 81	- 39
296	- 118	- 37
336	- 140	- 29

RUN No. 15 Date: 27 April 1949

RUN No. 16 Date: 27 April 1949

Type: Combined Compression and
Shear. Constant shear force
along the diagonal 118
pounds.

Type: Combined Compression and Shear.
Constant shear force along the
diagonal 246 pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate
142	- 99	- 70
172	- 111	- 73
214	- 132	- 69
236	- 146	- 68

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate
66	- 51	- 21
104	- 68	- 21
142	- 89	- 17
166	- 99	- 14

Condition of the sea on 1st April 1918

Run No. 12 Date: 1st April 1918

Types: Combined Compression and Tension
 Direction of force: Along the diagonal line
 Direction of pressure: Along the diagonal line

Along Diagonal (lb-in.)		Along Diagonal (lb-in.)		Along Diagonal (lb-in.)		Along Diagonal (lb-in.)	
Top of Plate	Bottom of Plate	Top of Plate	Bottom of Plate	Top of Plate	Bottom of Plate	Top of Plate	Bottom of Plate
48	4	1	8	18	4	48	4
51	10	10	10	22	4	51	4
53	10	10	24	24	4	53	4
55	10	10	24	24	4	55	4
57	10	10	24	24	4	57	4
59	10	10	24	24	4	59	4
61	10	10	24	24	4	61	4
63	10	10	24	24	4	63	4
65	10	10	24	24	4	65	4
67	10	10	24	24	4	67	4
69	10	10	24	24	4	69	4
71	10	10	24	24	4	71	4
73	10	10	24	24	4	73	4
75	10	10	24	24	4	75	4
77	10	10	24	24	4	77	4
79	10	10	24	24	4	79	4
81	10	10	24	24	4	81	4

Run No. 13 Date: 2nd April 1918

Types: Combined Compression and Tension
 Direction of force: Along the diagonal line
 Direction of pressure: Along the diagonal line

Along Diagonal (lb-in.)		Along Diagonal (lb-in.)		Along Diagonal (lb-in.)		Along Diagonal (lb-in.)	
Top of Plate	Bottom of Plate	Top of Plate	Bottom of Plate	Top of Plate	Bottom of Plate	Top of Plate	Bottom of Plate
100	4	4	40	100	4	100	4
102	4	4	40	102	4	102	4
104	4	4	40	104	4	104	4
106	4	4	40	106	4	106	4
108	4	4	40	108	4	108	4
110	4	4	40	110	4	110	4
112	4	4	40	112	4	112	4
114	4	4	40	114	4	114	4
116	4	4	40	116	4	116	4
118	4	4	40	118	4	118	4
120	4	4	40	120	4	120	4
122	4	4	40	122	4	122	4
124	4	4	40	124	4	124	4
126	4	4	40	126	4	126	4
128	4	4	40	128	4	128	4
130	4	4	40	130	4	130	4

Specimen: Plate No. 4

Plate thickness: 0.0395 inches

Conditions: Lateral supports of cross section 3/16 inch by 1 inch, bolt holes 11/64 inch diameter, lateral supports and plate specimen joined by 8-32 size screws, finger tight. Shear force attachments connected to the plate specimen.

RUN No. 17 Date: 30 April 1949

Type: Pure Compression

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	<u>Top of Plate</u>	<u>Bottom of Plate</u>
112	- 21	- 30
192	- 41	- 59
276	- 49	- 98
312	- 47	- 121
352	- 38	- 150
400	- 22	- 181

RUN No. 18 Date: 30 April 1949

RUN No. 19 Date: 30 April 1949

Type: Combined Compression and Shear. Constant shear force along the diagonal 191 pounds.

Type: Combined Compression and Shear. Constant shear force along the diagonal 392 pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)		Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	<u>Top of Plate</u>	<u>Bottom of Plate</u>		<u>Top of Plate</u>	<u>Bottom of Plate</u>
0	- 10	- 1	0	+ 17	+ 22
88	- 22	- 22	48	+ 10	+ 13
112	- 29	- 44	96	+ 8	- 4
164	- 21	- 80	132	+ 2	- 18
192	- 10	- 101	172	+ 1	- 36
			204	+ 6	- 65

Geological Profile No. 4. This profile was made by the U.S. Geological Survey, and shows the general character of the rocks of the area. The profile is based on the work of the U.S. Geological Survey, and is not to be taken as a representation of the actual topography of the area.

Scale: 1 inch = 1 mile. Date: April 1901.

Top of Profile

Top of Profile	Top of Profile	Top of Profile
Feet	Feet	Feet
100	100	100
200	200	200
300	300	300
400	400	400
500	500	500
600	600	600
700	700	700
800	800	800
900	900	900
1000	1000	1000

Scale: 1 inch = 1 mile. Date: April 1901.

Geological Profile No. 4. This profile was made by the U.S. Geological Survey, and shows the general character of the rocks of the area. The profile is based on the work of the U.S. Geological Survey, and is not to be taken as a representation of the actual topography of the area.

Top of Profile	Top of Profile	Top of Profile	Top of Profile	Top of Profile	Top of Profile
Feet	Feet	Feet	Feet	Feet	Feet
100	100	100	100	100	100
200	200	200	200	200	200
300	300	300	300	300	300
400	400	400	400	400	400
500	500	500	500	500	500
600	600	600	600	600	600
700	700	700	700	700	700
800	800	800	800	800	800
900	900	900	900	900	900
1000	1000	1000	1000	1000	1000

Specimen: Plate No. 4

Plate thickness: 0.0395 inches

Conditions: The same as Run No. 17.

RUN No. 20 Date: 30 April 1949

RUN No. 21 Date: 30 April 1949

Type: Combined Compression and Shear. Constant shear force along the diagonal 630 pounds.

Type: Combined Compression and Shear. Constant shear force along the diagonal 875 pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

0	+ 2	+ 11
---	-----	------

0	- 11	- 11
---	------	------

84	- 11	- 10
----	------	------

104	- 31	- 29
-----	------	------

132	- 22	- 29
-----	------	------

144	- 42	- 34
-----	------	------

164	- 31	- 38
-----	------	------

184	- 55	- 38
-----	------	------

200	- 32	- 49
-----	------	------

224	- 70	- 47
-----	------	------

244	- 31	- 68
-----	------	------

276	- 73	- 54
-----	------	------

264	- 29	- 79
-----	------	------

304	- 74	- 59
-----	------	------

328	- 80	- 58
-----	------	------

364	- 72	- 68
-----	------	------

392	- 53	- 88
-----	------	------

420	+ 17	- 158
-----	------	-------

Revised: 1944-10-14

Plate thickness: 0.030 inches

Condition: The test is Run No. 1.

Run No. 10 Date: 23 April 1944 Run No. 11 Date: 23 April 1944

Type: Combined Compression and Shear
 Shear, Constant shear force
 along the diagonal 850
 pounds.
 Type: Combined Compression and Shear
 Constant shear force along the
 diagonal 875 pounds.

Load (lbs)	Top of Plate	Bottom of Plate	Strain Gages (mils-in.)	Load (lbs)	Top of Plate	Bottom of Plate	Strain Gages (mils-in.)
0	+	+	11	0	-	-	11
84	-	-	11	104	-	-	11
168	-	-	11	144	-	-	11
252	-	-	11	184	-	-	11
336	-	-	11	224	-	-	11
420	-	-	11	264	-	-	11
504	-	-	11	304	-	-	11
588	-	-	11	344	-	-	11
672	-	-	11	384	-	-	11
756	-	-	11	424	-	-	11
840	-	-	11	464	-	-	11
924	-	-	11	504	-	-	11
1008	-	-	11	544	-	-	11
1092	-	-	11	584	-	-	11
1176	-	-	11	624	-	-	11
1260	-	-	11	664	-	-	11
1344	-	-	11	704	-	-	11
1428	-	-	11	744	-	-	11
1512	-	-	11	784	-	-	11
1596	-	-	11	824	-	-	11
1680	-	-	11	864	-	-	11
1764	-	-	11	904	-	-	11
1848	-	-	11	944	-	-	11
1932	-	-	11	984	-	-	11
2016	-	-	11	1024	-	-	11
2100	-	-	11	1064	-	-	11
2184	-	-	11	1104	-	-	11
2268	-	-	11	1144	-	-	11
2352	-	-	11	1184	-	-	11
2436	-	-	11	1224	-	-	11
2520	-	-	11	1264	-	-	11
2604	-	-	11	1304	-	-	11
2688	-	-	11	1344	-	-	11
2772	-	-	11	1384	-	-	11
2856	-	-	11	1424	-	-	11
2940	-	-	11	1464	-	-	11
3024	-	-	11	1504	-	-	11
3108	-	-	11	1544	-	-	11
3192	-	-	11	1584	-	-	11
3276	-	-	11	1624	-	-	11
3360	-	-	11	1664	-	-	11
3444	-	-	11	1704	-	-	11
3528	-	-	11	1744	-	-	11
3612	-	-	11	1784	-	-	11
3696	-	-	11	1824	-	-	11
3780	-	-	11	1864	-	-	11
3864	-	-	11	1904	-	-	11
3948	-	-	11	1944	-	-	11
4032	-	-	11	1984	-	-	11
4116	-	-	11	2024	-	-	11
4200	-	-	11	2064	-	-	11
4284	-	-	11	2104	-	-	11
4368	-	-	11	2144	-	-	11
4452	-	-	11	2184	-	-	11
4536	-	-	11	2224	-	-	11
4620	-	-	11	2264	-	-	11
4704	-	-	11	2304	-	-	11
4788	-	-	11	2344	-	-	11
4872	-	-	11	2384	-	-	11
4956	-	-	11	2424	-	-	11
5040	-	-	11	2464	-	-	11
5124	-	-	11	2504	-	-	11
5208	-	-	11	2544	-	-	11
5292	-	-	11	2584	-	-	11
5376	-	-	11	2624	-	-	11
5460	-	-	11	2664	-	-	11
5544	-	-	11	2704	-	-	11
5628	-	-	11	2744	-	-	11
5712	-	-	11	2784	-	-	11
5796	-	-	11	2824	-	-	11
5880	-	-	11	2864	-	-	11
5964	-	-	11	2904	-	-	11
6048	-	-	11	2944	-	-	11
6132	-	-	11	2984	-	-	11
6216	-	-	11	3024	-	-	11
6300	-	-	11	3064	-	-	11
6384	-	-	11	3104	-	-	11
6468	-	-	11	3144	-	-	11
6552	-	-	11	3184	-	-	11
6636	-	-	11	3224	-	-	11
6720	-	-	11	3264	-	-	11
6804	-	-	11	3304	-	-	11
6888	-	-	11	3344	-	-	11
6972	-	-	11	3384	-	-	11
7056	-	-	11	3424	-	-	11
7140	-	-	11	3464	-	-	11
7224	-	-	11	3504	-	-	11
7308	-	-	11	3544	-	-	11
7392	-	-	11	3584	-	-	11
7476	-	-	11	3624	-	-	11
7560	-	-	11	3664	-	-	11
7644	-	-	11	3704	-	-	11
7728	-	-	11	3744	-	-	11
7812	-	-	11	3784	-	-	11
7896	-	-	11	3824	-	-	11
7980	-	-	11	3864	-	-	11
8064	-	-	11	3904	-	-	11
8148	-	-	11	3944	-	-	11
8232	-	-	11	3984	-	-	11
8316	-	-	11	4024	-	-	11
8400	-	-	11	4064	-	-	11
8484	-	-	11	4104	-	-	11
8568	-	-	11	4144	-	-	11
8652	-	-	11	4184	-	-	11
8736	-	-	11	4224	-	-	11
8820	-	-	11	4264	-	-	11
8904	-	-	11	4304	-	-	11
8988	-	-	11	4344	-	-	11
9072	-	-	11	4384	-	-	11
9156	-	-	11	4424	-	-	11
9240	-	-	11	4464	-	-	11
9324	-	-	11	4504	-	-	11
9408	-	-	11	4544	-	-	11
9492	-	-	11	4584	-	-	11
9576	-	-	11	4624	-	-	11
9660	-	-	11	4664	-	-	11
9744	-	-	11	4704	-	-	11
9828	-	-	11	4744	-	-	11
9912	-	-	11	4784	-	-	11
10000	-	-	11	4824	-	-	11

Specimen: Plate No. 5

Plate thickness: 0.064 inches

Conditions: Lateral supports of cross section 3/16 inch by 1 inch, bolt holes 11/64 inch diameter, lateral supports and plate specimen joined by 8-32 size screws, finger tight. Shear force attachments connected to plate specimen.

RUN No. 22 Date: 3 May 1949

RUN No. 23 Date: 4 May 1949

Type: Pure Compression

Type: Combined Compression and Shear.
Constant shear force along the diagonal 474 pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)		Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate		Top of Plate	Bottom of Plate
172	- 31	- 25	0	- 71	- 57
272	- 50	- 43	268	- 133	- 79
376	- 68	- 58	460	- 170	- 88
504	- 90	- 76	668	- 211	- 102
568	- 103	- 85	852	- 245	- 114
680	- 125	- 103	1052	- 275	- 123
772	- 143	- 114	1256	- 311	- 131
872	- 156	- 123	1296	- 316	- 130
972	- 170	- 132	1416	- 324	- 129
1072	- 189	- 136	1456	- 332	- 128
1172	- 200	- 143	1492	- 334	- 127
1272	- 213	- 144			
1352	- 224	- 148			
1460	- 240	- 144			
1548	- 250	- 143			
1580	- 251	- 143			
1620	- 254	- 142			
1632	- 259	- 142			

Specimen: Plate No. 5

Plate thickness: 0.064 inches

Conditions: The same as Run No. 22

RUN No. 24 Date: 4 May 1949

RUN No. 25 Date: 4 May 1949

Type: Combined Compression and
Shear. Constant shear
force along the diagonal
1010 pounds.

Type: Combined Compression and
Shear. Constant shear
force along the diagonal
1660 pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)		Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate		Top of Plate	Bottom of Plate
0	- 71	- 18	0	- 99	+ 6
280	- 143	- 47	492	- 215	- 20
456	- 180	- 61	700	- 251	- 26
680	- 222	- 78	876	- 279	- 26
868	- 257	- 87	920	- 281	- 26
1068	- 287	- 88	960	- 285	- 26
1264	- 303	- 87	1000	- 291	- 25
1344	- 310	- 85	1036	- 293	- 25

Specimen: Plate No. 6

Plate thickness: 0.065 inches.

Conditions: Lateral supports of cross section 3/16 inch by 1 inch, bolt holes 11/64 inch diameter, lateral supports and plate specimen joined by 8-32 size screws, finger tight. Shear force attachments connected to plate specimen on each side by Pins III and IV only.

RUN No. 26 Date: 5 May 1949

Type: Pure Compression

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate
260	- 46	- 40
664	- 123	- 82
860	- 154	- 92
1064	- 191	- 99
1240	- 220	- 101
1336	- 233	- 101
1408	- 241	- 99
1444	- 243	- 98

Condition: Lateral supports at cross section 1/16 inch by 1 inch, bolt holes 1/16 inch diameter, lateral supports and plate specimen joined by 8-32 size screws. Three 1/16 inch square force transducers connected to plate specimen on each side by pins III and IV only.

Run No. 20 Date: 8 May 1960

Type: Pure Compression

Load (lbs)	Displacement (in.)	Strain Gages	
		Top of Plate	Bottom of Plate
000	- .00	- .00	- .00
004	- .01	- .01	- .01
008	- .02	- .02	- .02
1004	- .04	- .04	- .04
1008	- .05	- .05	- .05
1009	- .06	- .06	- .06
1010	- .07	- .07	- .07
1011	- .08	- .08	- .08
1012	- .09	- .09	- .09

Specimen: Plate No. 6

Plate thickness: 0.065 inches.

Conditions: The same as Run No. 26

RUN No. 27 Date: 5 May 1949

RUN No. 28 Date: 5 May 1949

Type: Combined Compression and Shear. Constant shear force along the diagonal 474 pounds.

Type: Combined Compression and Shear. Constant shear force along the diagonal 1067 pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)		Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate		Top of Plate	Bottom of Plate
0	- 39	- 11	0	- 70	- 31
316	- 115	- 48	312	- 152	- 40
704	- 207	- 73	512	- 201	- 49
1000	- 263	- 89	700	- 239	- 61
1128	- 275	- 96	904	- 276	- 69
1216	- 282	- 96	1024	- 292	- 70
1252	- 287	- 96	1048	- 297	- 71
1300	- 289	- 93	1096	- 301	- 72
			1132	- 302	- 75
			1176	- 306	- 76
			1212	- 310	- 77
			1260	- 311	- 77
			1288	- 311	- 76
			1340	- 316	- 76

Specimen: Plate No. 6

Plate thickness: 0.065 inches

Conditions: The same as Run No. 26

RUN No. 29 Date: 6 May 1949

RUN No. 30 Date: 6 May 1949

Type: Combined Compression and Shear. Constant shear force along the diagonal 530 pounds.

Type: Combined Compression and Shear. Constant shear force along the diagonal 1110 pounds.

Axial Compressive Load (lbs)	Strain Gauge (micro-in.)		Axial Compressive Load (lbs)	Strain Gauge (micro-in.)	
	Top of Plate	Bottom of Plate		Top of Plate	Bottom of Plate
0	- 59	- 36	0	- 98	- 25
296	- 120	- 64	364	- 184	- 43
492	- 160	- 90	492	- 210	- 50
704	- 207	- 111	588	- 235	- 52
900	- 248	- 126	680	- 249	- 59
1012	- 267	- 140	764	- 260	- 60
1096	- 273	- 142	840	- 261	- 61
1132	- 277	- 143	924	- 281	- 64
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Specimen: Plate No. 7

Plate thickness: 0.030 inches

Conditions: Lateral supports of cross section 3/16 inch by 1 inch, bolt holes 11/64 inch diameter, lateral supports and plate specimen joined by 8-32 size screws, finger tight. Shear force attachments connected to plate specimen on each side by Pins III and IV only.

RUN No. 31 Date: 6 May 1949

RUN No. 32 Date: 6 May 1949

Type: Pure Compression

Type: Pure Compression

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

60	- 23	- 17
----	------	------

136	- 59	- 32
-----	------	------

216	- 108	- 46
-----	-------	------

296	- 158	- 37
-----	-------	------

336	- 187	- 27
-----	-------	------

384	- 223	- 6
-----	-------	-----

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

60	- 23	- 19
----	------	------

100	- 41	- 26
-----	------	------

140	- 61	- 37
-----	------	------

176	- 85	- 40
-----	------	------

220	- 110	- 42
-----	-------	------

264	- 141	- 40
-----	-------	------

308	- 170	- 32
-----	-------	------

336	- 200	- 22
-----	-------	------

RUN No. 33 Date: 6 May 1949

RUN No. 34 Date: 6 May 1949

Type: Combined Compression and Shear. Constant shear force along the diagonal 19 pounds.

Type: Combined Compression and Shear. Constant shear force along the diagonal 57 pounds.

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

0	- 16	- 18
---	------	------

112	- 71	- 49
-----	------	------

184	- 111	- 53
-----	-------	------

272	- 171	- 45
-----	-------	------

Axial Compressive Load (lbs)	Strain Gauges (micro-in.)	
	Top of Plate	Bottom of Plate

0	- 3	1
---	-----	---

56	- 22	- 13
----	------	------

96	- 38	- 24
----	------	------

132	- 58	- 31
-----	------	------

180	- 87	- 37
-----	------	------

216	- 112	- 38
-----	-------	------

APPENDIX D
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DATE DUE

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1. *Thymus*

1941-42
1942-43
1943-44

1917

W. T. M. 4
1903
1904

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U. T. I. 10
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AUG 31

BINDERY

Thesis 10416
B2 Ballard

AUTHOR

Investigation of the effects of

TITLE shear on the compressive
strength of plating

DATE LOANED	BORROWER'S NAME	DATE RETURNED

Thesis 10416
B2 Ballard

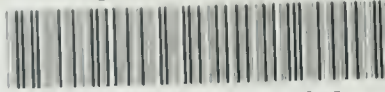
Investigation of the
effects of shear on the com-
pressive strength of plating.

U. S. Naval Postgraduate School
Monterey, California



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An investigation of the effects of shear



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